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Prepared for the
Transportation Development Centre
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by

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16. Abstract

This report presents the results of investigations conducted by the Canada Centre for Mineral and Energy Technology on the development of capping systems for sealing pyritic rock outcrops at the Halifax International Airport.

In-house investigations at CANMET have led to the development of a polypropylene fibre-reinforced, high-volume fly ash shotcrete system for capping the rock outcrops. The system has satisfactory workability and strength properties, very low permeability, low drying shrinkage, adequate ductility and toughness characteristics, and can be placed using conventional, wet shotcrete techniques.

The investigations performed by Hardy BBT Ltd., Vancouver, which involved shotcreting of large test panels, have confirmed CANMET studies.

The investigations performed by D. Comrie Consultants, Toronto, failed to yield any satisfactory geopolymer capping system.

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16. Résumé

Ce rapport donne les résultats de la recherche menée par le Centre canadien de la technologie des minéraux et de l'énergie (CANMET) sur un revêtement pour l'étanchéification des affleurements ardoisiers à teneur élevée en pyrite dans le sol de l'aéroport international d'Halifax.

La recherche à l'interne menée par CANMET a débouché sur une gunite renfermant une forte proportion de cendres volantes renforcées de fibres de polypropylène, dont les avantages sont sa bonne ouvrabilité et ses propriétés de résistance, une très faible perméabilité, peu de retrait en durcissant et des caractéristiques adéquates de ductilité et de ténacité. Enfin, il se met en place comme une gunite ordinaire.

Les recherches faites par Hardy BBT Ltd. à Vancouver sur le gunitage de grands panneaux ont confirmé les résultats obtenus par CANMET.

Quant aux recherches menés par D. Comrie Consultants de Toronto sur un revêtement à base de polymère, elles n'ont pas été couronnées de succès.

17. Mots clés

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SUMMARY

This report presents the results of investigations performed under a research and evaluation program conducted by the Canada Centre for Mineral and Energy Technology to develop cementitious-based and geopolymer capping systems for sealing pyritic rock outcrops at the Halifax International Airport.

Airport construction activities over the years have exposed large areas of pyritic slate bedrock around the Halifax airport. This pyritic rock is susceptible to attack because of its exposure to the atmosphere, penetrating rain and snow melt. This leads to the generation of acid leachates and other aggressive effluents which may carry with them other toxic elements. The release of these leachates into the local drainage system can lead to serious health and environmental problems. One of the simplest and most effective solutions to prevent or reduce the production of the above effluents is by covering the exposed rock surfaces with a low permeability capping material. Cementitious-based wet shotcrete and geopolymer systems have been proposed as being the most promising technologies to achieve the above.

The investigations were performed in three parts: Part I of the investigations was performed in-house at CANMET, Ottawa, to develop cementitious-based capping systems; Part II of the investigations was subcontracted to Hardy BBT Ltd., Vancouver, to expand on the work performed at CANMET; and Part III of the investigations was subcontracted to D. Comrie Consultants Ltd., Mississauga, to develop geopolymer materials for sealing the rock outcrops.

In-house research at CANMET has led to the development of a polypropylene fibre-reinforced, high-volume fly ash shotcrete system for capping the rock outcrops. This system has low cement content, incorporates large volumes of low-calcium fly ash and large percentages of polypropylene fibre. The concrete so developed has satisfactory workability, good strength and durability properties, very low permeability, low drying shrinkage, adequate ductility and toughness characteristics, and can be placed using conventional wet shotcrete techniques. The estimated placement cost is about 12 dollars per square metre with an average thickness of about 50 mm.

Investigations performed at Hardy BBT Ltd., Vancouver, have confirmed studies at CANMET, and their studies on shotcreting large panels have further reinforced CANMET studies.

The investigations performed by D. Comrie Consultants Ltd. on geopolymer systems were limited in nature and do not allow any satisfactory conclusions to be drawn as to their field application as capping materials.

It is, therefore, recommended that the cementitious-based system developed at CANMET, and confirmed by the studies at Hardy BBT Ltd., be given serious consideration for capping pyritic rock outcrops at Halifax International Airport, Halifax.

SOMMAIRE

Ce rapport donne les résultats de la recherche menée par le Centre canadien de la technologie des minéraux et de l'énergie (CANMET), au titre d'un programme de recherche et d'évaluation visant à réaliser des revêtements à base de liants hydrauliques et à base de polymère, destinés à étanchéifier les affleurements ardoisiers à teneur élevée en pyrite présents dans le sol de l'aéroport international d'Halifax.

Au fil des ans, la construction aéroportaire a mis en évidence autour de cet aéroport de vastes zones géologiques formées d'ardoise pyritifère qui, en raison de leur affleurement, se trouvent exposées aux intempéries, produisant des ruissellements acides et autres effluents nocifs, voire toxiques. En s'infiltrant dans le système de drainage, ils peuvent avoir de graves conséquences et être nuisibles tant à la santé qu'à l'environnement. La parade la plus simple et la plus efficace est de revêtir les affleurements d'un dispositif d'étanchéité. Des revêtements de gunite à base de liants hydrauliques ou à base de polymère ont été proposés comme étant des méthodes très prometteuses.

La recherche s'est déroulée en trois temps : 1) recherche à l'interne par CANMET à Ottawa visant à réaliser un revêtement à base de liants hydrauliques; 2) recherche sous-traitée à Hardy BBT Ltd. de Vancouver et partant des résultats obtenus par CANMET, et 3) recherche confiée à D. Comrie Consultants Ltd. de Mississauga, visant à réaliser un revêtement à base de polymère servant de dispositif d'étanchéité.

La recherche menée à l'interne par CANMET a débouché sur une gunite renfermant une forte proportion de cendres volantes renforcées de fibres de polypropylène, dont les avantages sont sa faible teneur en ciment, sa forte proportion de cendres volantes à faible teneur en calcium et sa forte proportion de fibres de polypropylène. Le béton ainsi obtenu possède une bonne ouvrabilité, de bonnes propriétés de résistance, une très faible perméabilité, peu de retrait en durcissant et des caractéristiques adéquates de ductilité et de ténacité. Enfin,il se met en place comme une gunite ordinaire, le coût de la mise en oeuvre étant estimé à quelque 12 dollars le mètre carré, à une épaisseur moyenne de 50 mm.

Les recherches faites par Hardy BBT Ltd. de Vancouver ont confirmé les résultats obtenus par CANMET, et étayés par les essais de gunitage de grands panneaux.

Quant aux recherches menées par D. Comrie Consultants Ltd. sur le revêtement à base de polymère, elles n'ont pas été couronnées de succès.

Il est donc recommandé que le revêtement à base de liants hydrauliques, mis au point par CANMET et validé par Hardy BBT Ltd., soit sérieusement envisagé comme une option valable pour l'étanchéification des affleurements ardoisiers.

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ANNEX 2: REPORT ON PHASE II INVESTIGATIONS BY HARDY BBT LTD.

ANNEX 3: REPORT ON INVESTIGATIONS BY COMRIE CONSULTANTS LTD.

INTRODUCTION

Some exposed rock outcrops are susceptible to attack because of their exposure to the atmosphere, penetrating rain and snow melt. This leads to the generation of acid leachates and other aggressive effluents which may carry with them other toxic elements. The release of these leachates into the local drainage system can lead to serious health and environmental problems.

A key element in reducing aggressive leachates is to eliminate or reduce the amount of water infiltrating the rock outcrops. The complete elimination of rain water and snow melt entering the surface is not completely feasible. The next best solution is to reduce the above amount; this can be achieved by providing a gradient and capping the exposed surfaces. The gradient will provide fast surface water run off and a low permeability capping material would reduce significantly the water penetration. Any water run off would have to be collected, treated, and diverted to natural streams.

In 1988, Transport Canada approached CANMET to undertake, under contract, the development of a cementitious-based material which could be used as a possible capping system for the pyritic rock outcrops at and around Halifax International Airport. The total area needing such coverage is more than 50 hectares.

OBJECTIVE OF THE STUDY

The objectives of the study were to determine the properties of fibre-reinforced high-volume fly ash concrete and then try to establish the optimum in water-to-(cement + fly ash) ratio, cement content, cementitious materials content, fibre content and length of fibre for the type of concrete to be used in shotcreting applications.

The study was divided into three parts. Part I of the study was to be performed at CANMET to develop the basic mixture proportions and performance data of the new concrete.

The second part of the study was to be subcontracted to Hardy BBT Ltd. to build on the work performed at CANMET and to shotcrete large panels with the new system.

The third part of the study was to be performed by Comrie Ltd., Toronto, to develop geopolymers as an alternative capping material.

PART I: INVESTIGATIONS AT CANMET

PHASE A OF STUDIES AT CANMET

Scope

In this phase of the study, a total of eighteen 0.07 m^3 concrete mixtures involving 40 batches were made. The water-to-(cement + fly ash) ratio (W/(C+FA)) of the mixtures ranged from 0.29 to 0.36. Concretes incorporating 4 kg and 5 kg of polypropylene fibre per cubic metre and concretes without fibre were made. Only one type and one length of the fibre was used. All mixtures were air-entrained and superplasticized. From all concrete mixtures, specimens were subjected to the determination of compressive and flexural strengths, modulus of elasticity, flexural toughness and drying shrinkage. Test specimens from some of the concrete mixtures were also tested for the determination of impact resistance, chloride-ion diffusion and resistance to rapid freezing and thawing cycling.

Concrete Mixtures

The concrete mixtures were made at CANMET between November 1988 and February 1989 using the following materials and mixture proportions:

Cement

Normal portland cement, ASTM Type I, was used in all concrete mixtures. Its physical properties and chemical analysis are given in Table 1.

Fly Ash

The fly ash used was low-calcium type (ASTM Class F), and was obtained from a source in Nova Scotia. Its physical properties and chemical analysis are given in Table 1.

Aggregates

The fine aggregate used for all mixtures was local natural sand. The coarse aggregate was pea gravel from the Halifax area. The fine aggregate was separated into different size fractions that were then recombined to a specific grading. The pea gravel was used as received but its grading met the ACI 506.2 specification. The specified grading (grading no. 2) used for the mixtures is given in Table 2.

Fibre

The polypropylene fibre used was a 38-mm long fibre from Forta Corporation Limited, and was designated as Type A.

Superplasticizer

A sulphonated naphthalene formaldehyde condensate of Japanese origin was used. This superplasticizer is available as a dark brown aqueous solution with 42% solids, having a density of 1200 kg/m^3.

Air-entraining admixture

A synthetic resin type of air-entraining admixture was used in all mixtures.

Mixture Proportions

The proportioning of the concrete mixtures is summarized in Table 3. For all mixtures, the graded coarse and fine aggregates were weighed in room-dry conditions. The coarse aggregate was then immersed in water for 24 h, the excess water was decanted and the water retained by the aggregate was determined by the weight difference. A predetermined amount of water was added to the fine aggregate which was then allowed to stand for 24 h.

The concrete mixtures were made with W/(C+FA) of 0.36, 0.32 and 0.29. For each water-to-(cement + fly ash) ratio, the mixtures were proportioned for two cement contents, 125 and 150 kg per cubic meter. Also, for each W/(C + FA) and cement content, three fibre contents, 0, 4 and 5 kg per cubic meter were used.

Two batches were made for each mixture except in four instances where three batches were necessary to obtain sufficient test specimens for determining the mechanical properties and resistance to rapid freezing and thawing cycling.

The concrete mixtures were made in a laboratory counter-current mixer with fly ash added as a separate ingredient. A certain amount of superplasticizer was added to the mixtures before the addition of the fibres, and the concrete was mixed for 4 minutes, then the fibres were incorporated together with more superplasticizer in order to obtain sufficient workability. The concretes were then mixed for two additional minutes in order to obtain a good dispersion of the fibres.

Properties of Fresh Concrete

The properties of the freshly mixed concrete, i.e., slump, unit weight and air content are given in Table 3.

Preparation and Casting of Test Specimens

In general, twelve 152 x 305-mm cylinders, twelve 76 x 102 x 406-mm and four 102 x 102 x 381-mm prisms were made from each concrete mixture. For some mixtures, 102 x 203-mm cylinders and 152 x 51-mm disks were also made. Two batches of each mixture were necessary to obtain the required number of specimens.

The 152 x 305-mm cylinders were used for the determination of compressive strength and Young's modulus of elasticity. The 76 x 102 x 406-mm prisms were used for determining the flexural strength and drying shrinkage of concrete. The 102 x 102 x 381-mm prisms were used for the determination of the flexural toughness of concrete. The 102 x 203-mm cylinders were used for the determination of the chloride ion diffusion and the disks were tested for impact resistance.

A third batch was made for four of the concrete mixtures. From this batch, four 152 x 305-mm cylinders and eight 76 x 102 x 406-mm prisms were made. The cylinders were tested in compression, and the prisms were used for determining the freezing and thawing resistance of concrete.

All the specimens were cast in two layers, each layer being compacted by an internal vibrator for the large cylinders and a vibrating table for the small cylinders, the prisms and the disks.

After casting, all the moulded specimens were covered with water saturated burlap, and left in the casting room at 23 ± 1.7°C and 50% relative humidity for 24 h. They were then demoulded and transferred to the moist-curing room at 100% relative humidity until required for testing, with the exception of the prisms for drying shrinkage tests. These prisms were stored in lime-saturated water.

Testing of Specimens

The testing schedule is shown in Table 6. As far as possible, all testing was performed in accordance with the ASTM standard procedures. All specimens for compression testing were capped with a thin layer of high-strength sulphur capping compound before testing at different ages. At 14 and 91 days, two 76 x 102 x 406-mm and two 102 x 102 x 381-mm prisms from each mixture were removed from the moist curing room; the 76 x 102 x 406-mm prisms were tested in flexure whereas the 102 x 102 x 381-mm prisms were used for the determination of the flexural toughness of concrete. The drying shrinkage tests on the test prisms were commenced after an initial curing period of seven days in lime-saturated water. Shrinkage strains were monitored for a period of 224 days of air drying at 23 ± 1.7°C and 50 ± 4% relative humidity. The impact resistance of concrete was determined at 28 days on the concrete disks using the impact strength test described in ACI Manual of concrete practice, fibre reinforced concrete testing (ACI 544.2R).

Chloride-ion diffusion into concrete was measured by the rapid chloride permeability test (AASHTO, T277-83). The rapid freezing and thawing test, ASTM C666 procedure A, was carried out on prisms from four of the concrete mixtures. Test prisms were subjected to freezing and thawing cycling after initial moist-curing periods of 14 and 91 days. The freezing and thawing test specimens had their lengths measured, were weighed, and tested by resonant frequency and ultrasonic pulse velocity methods at approximately every 75-cycle interval. The freezing and thawing testing was terminated at the completion of 300 cycles. Following this, both the reference and the freezing and thawing prisms were tested in flexure.

Test Results and Their Analysis

A summary of the compressive and flexural strength and the modulus of elasticity test results is given in Table 9 for ages up to one year. Flexural toughness test results of concrete prisms at 14 and 91 days are given in Tables 12 and 15 respectively. Impact test results are shown in Table 18. The chloride-ion diffusion test was performed only on mixtures 9, 10 and 12, and the results are given in Table 19. The drying shrinkage test results are summarized in Table 20. A summary of the test results after 300 cycles of freezing and thawing, including durability factors is given in Table 22 for prisms moist cured for 14 days, and in Table 24 for prisms moist cured for 91 days before testing. The flexural strengths of the reference prisms, and the test prisms after 300 cycles of freezing and thawing are shown in Tables 23 and 25. The changes in length, resonant frequency, pulse velocity and weight of the reference prisms and the prisms subjected to freezing and thawing cycling are shown in Tables 26 to 29 for prisms moist cured for 14 days, and in Tables 30 to 32 for prisms moist cured for 91 days before testing. In this last case no length measurements of the prisms were taken.

Discussion

Slump

One of the requirement of the test program was that the slump be maintained at 75 ± 25 mm for all mixtures, and this was to be achieved by varying the dosage of the superplasticizer in the concrete. This was generally achieved, but there were minor exceptions (Table 3). All mixtures, independently of the fibre content and the proportioning of cementitious materials had satisfactory workability, even for those fibre concretes which had particularly low slumps. For fibre concretes, the slump test obviously does not provide the same indication of workability as it does for plain concrete.

Superplasticizer Dosage Requirement

Whereas the superplasticizer dosage requirement to maintain a given slump was essentially independent of the cement factor used, it was found to be significantly affected by both the total cementitious content and the fibre content of the mixture. The superplasticizer dosage decreased from an average value of 5.5 L/m^3 at a total cementitious material content of 350 kg/m^3 to an average of 4.4 L/m^3 at a cementitious material content of 450 kg/m^3, indicating the beneficial effect of the fly ash in increasing the workability. The superplasticizer dosage requirement increased with the content of fibre in the mixture, with the dosage ranging from an average value of 3.5 L/m^3 for the plain mixtures to the average values of 4.8 and 6.4 L/m^3 for mixtures incorporating 4 and 5 kg/m^3 of fibre, respectively. The data suggest that the effect is a function of the fibre loading, and the dosage increases rapidly as the fibre content is increased.

Air Entrainment

In these investigations, an air content of 8 ± 1 per cent was specified for all the mixtures. This was based on the typical minimum levels of entrained air that would need to be entrained in this type of concrete to ensure adequate freezing and thawing durability of the material in shotcrete applications. As shown in Table 3, no problems were encountered in meeting the above requirements for the concrete mixtures investigated.

Compressive Strength

The compressive strength of the concrete test specimens was determined up to 365 days (Table 9). In general, the over-all strength development pattern in each case was typical of that for a low-cement content, high-volume fly ash concrete system, i.e., a relatively slow rate of gain in strength at ages up to 28 days followed by large gains at later ages as a result of the pozzolanic reaction. The levels of strength achieved for the various concretes ranged from about 15 to 20 MPa at 28 days, and from about 40 to 50 MPa at one year, indicating a two to three fold increase in the strength between the two ages.

The incorporation of the fibres in the concretes had, in general, no significant effect on the compressive strengths, although there were a few exceptions. These included some of the fibre concretes that had relatively low cementitious material content, for which the compressive strength was observed to be significantly inferior to that of the corresponding plain mixtures at all ages. Such results have not been explained; however, it may be noted that these mixtures, for a given workability, necessitated the largest superplasticizer dosages, and yielded the lowest values of unit weight of fresh concrete. This suggests that with high-volume fly ash concrete, using low water content and requiring large quantities of superplasticizer, proper fibre dispersion and full compaction of concrete may not be readily achieved with high dosages of fibre, unless the total cementitous material content is kept over a certain minimum level. In this investigation, such a minimum level would appear to have been of the order of 400 kg/m^3. It can be observed from the data in Table 9 that, while an increase in the fly ash content at a given cement level had apparently little influence on the compressive strength of plain concrete, it clearly had some beneficial effect on the strength of the fibre mixtures, especially at the lower total cementitious material content. Also, as might be expected, the mixtures with a cement content of 150 kg/m^3 produced slightly higher strengths than those with a cement content of 125 kg/m^3, independently of the fibre content. Within the range of mixture proportions investigated, the most efficient combinations in producing both the highest and most consistent compressive strength results for concrete incorporating fibres, were generally those having a cement content of 150 kg/m^3, a fly ash content of either 250 or 300 kg/m^3, and a corresponding W/C+FA of 0.32 or 0.29 respectively. The strength of these mixtures were, on the average, of the order of 12 MPa at 7 days, 21 MPa at 28 days and 52 MPa at 365 days.

Flexural Strength

Flexural strengths were determined at the ages of 14 and 91 days (Table 9). The strengths recorded were of the order of 2 to 2.5 MPa at 14 days and 4 to 5 MPa at 91 days for most of the mixtures. In general, the trends observed for the flexural strengths at the above ages were similar to those observed for the compressive strengths at the corresponding ages. The presence of the fibres at either dosage of 4 or 5 kg/m^3 in the concrete had little influence on the flexural strength of most of the concrete mixtures; the exceptions noted were the same as those observed for the compressive strengths, though in these cases, the effect was much less noticeable. Also, the concrete mixtures which yielded high compressive strengths, were also observed to produce the highest flexural strengths for concretes incorporating fibres.

Young's Modulus of Elasticity "E"

The Young's modulus of elasticity "E" for the concretes investigated was determined at the age of 91 days. The "E" values determined varied from about 27 to 34 GPa with an average value of about 30 GPa. The results were, to a large extent, a function of the compressive strength results at the same age, with variations in strength being generally reflected by variations of a lesser magnitude in modulus of elasticity, and this is in agreement with what is generally observed with conventional concrete. The presence of fibres had, once more, little effect on the test results.

Flexural Toughness

Flexural toughness tests were performed on concrete prisms at the ages of 14 and 91 days for all the mixtures incorporating fibres using procedures described in ASTM C 1018-85. These tests were aimed at determining the extent to which addition of polypropylene fibres at loadings of up to 5 kg/m^3 in the concrete mixtures improved the ductility characteristics of the concretes.

The test results, which are expressed in terms of toughness indices such as I_5, I_{10} and I_{30} calculated from the load-deflection curves, are given in Tables 12 and 15. Essentially, the above toughness indices enable actual performance to be compared with some readily understood reference level of performance. In this regard, values of 5.0, 10.0 and 30.0 for I_5, I_{10} and I_{30} correspond to linear elastic material behaviour up to first crack and perfectly plastic behaviour thereafter. Lower values indicate inferior performance. Index ratios such as I_{10}/I_5 and I_{30}/I_{10} are also used to evaluate toughness performance. In this case, values of 2.0 for I_{10}/I_5 and 3.0 for I_{30}/I_{10} indicates perfectly plastic behaviour between the deflections associated with the indices, and lower values again indicate inferior behaviour.

Though the toughness index values obtained for the concretes tested were clearly below the values indicated above, they were nevertheless indicative of good toughness properties. At the age of 14 days, the I_5 index values ranged from 3.3 to 4.0, whereas the values for I_{10} ranged from 6.0 to 7.7. These index values compare favourably with those observed with many commercially available steel fibres used at the rates of about 60 kg/m^3 of concrete. Further, the index ratio values obtained at 14 days indicate excellent performance of all concretes tested between deflections associated with indices of I_5 and I_{30}. The toughness index results at 91 days were slightly lower than those obtained at 14 days in all cases. This apparent loss of toughness with age is largely the result of a considerably higher first crack strength at the latter age. In general, an increase in the fibre loading from 4 to 5 kg/m^3 had little effect on the toughness values at the age of 14 days, however, it was found to contribute to a significant increase in these values at the age of 91 days. As expected, the mixture proportions appeared to have little influence on the toughness index values.

Impact Resistance

The impact resistance of the concretes investigated was determined at the age of 28 days for the concrete mixtures at both low and high cementitious material content levels. The testing which was carried out using ACI 544.2R-78 standard test procedures, was aimed at demonstrating the improved performance of concrete mixtures incorporating fibres when compared to plain concrete mixtures, and comparing the relative merits of concrete mixtures incorporating different amounts of fibres.

The test results are presented in Table 18; in general, they indicate greatly improved performance of all fibre concretes as compared to the non-fibre concretes. The impact energy or the number of blows necessary to initiate the first cracking was apparently unaffected by the presence of the fibre; however, the number of additional blows to propagate or open the cracks to the specified ultimate failure was less than a few for non-fibre concretes as compared to the numbers ranging from 32 to more than 140 for the fibre concretes. While the test demonstrated a much improved impact resistance of the fibre concretes, it gave no clear indication as to the effect of the mixture proportions or the effect of increasing the fibre content from 4 to 5 kg/m^3 on the impact resistance of the concrete. This could have been, however, masked by the relatively large variations in the test results generally associated with the test method used.

Resistance to Chloride-Ion Diffusion

Investigations previously performed at CANMET had indicated excellent performance of high-volume fly ash concrete with respect to its resistance to chloride-ion diffusion. In the present investigations, the chloride-ion diffusion tests were performed to verify whether previous findings still applied to the high-volume fly ash concretes which had slightly different mixture proportions, and also contained polypropylene fibre. The results obtained for the few selected mixtures tested in this phase are shown in Table 19. The results are expressed in terms of the total charge in coulombs which provides an indirect measure of the resistance of the material to the chloride-ion diffusion.

The values shown are similar to those previously reported for the high-volume fly ash concrete, and are indicative of a relatively high resistance of these concretes to chloride-ion diffusion as compared with conventional concretes. The presence of the fibres, at least up to a dosage of 5 Kg/m^3 of the particular fibre (Type A) used in this phase of the investigation, appeared to have no influence on the recorded performance. As noted in the previous studies on this type of concrete, the resistance of the moist-cured concrete to chloride-ion diffusion increased rapidly with age. At the age of 91 days, the level of resistance achieved was comparable to that generally observed with very dense, high-strength concrete systems.

Drying Shrinkage Strains

Drying shrinkage strains of the test prisms cast from the concretes investigated in this phase were monitored over a period of 224 days. The concrete was moist-cured for 7 days prior to drying, and this was to reflect curing requirements likely to be specified for the proposed applications of this type of concrete in the field.

The drying-shrinkage strains after various periods of drying are shown in Table 20. For each concrete, much of the strain was recorded within the first few weeks of drying, as is generally the case for conventional concrete, with about 75 to 85 per cent of the total strain being reached after only 28 days of drying. In general, the total drying shrinkage strains of the unrestrained concretes after 224 days of drying were essentially of the same order for all the concretes, i.e. 600 to 750 x 10^{-6}. The strains were apparently little affected by either the mixture proportions or the fibre content of the concretes. The observed total drying shrinkage strains were somewhat comparable to those generally observed for conventional concrete, and therefore could be considered satisfactory. In view of the very low water content of the concretes, the shrinkage strains might have been expected to be at a lower level; however, this was probably offset by factors such as mixture proportions and the maximum size (9-mm) of aggregate being used for these concretes.

Resistance to Repeated Cycles of Freezing and Thawing

The resistance of the concretes to the repeated cycles of freezing and thawing in water (ASTM C 666, Procedure A) was determined on test prisms cast from mixtures no. 3, 6, 15 and 18.

These concretes had a fibre content of 5 kg/m^3, and covered both lower and higher levels of W/(C + FA) for each of the two cement contents used. The testing was commenced after initial curing periods of 14 and 91 days to evaluate the effect of maturity of concrete at the time of exposure to the freezing and thawing cycling.

As shown in Tables 22 and 24, the durability factors ranged from 97 to 103 for 14-day moist-cured concretes, and from 92 to 96 for 91-day moist-cured concretes; these values of the durability factors indicate excellent resistance to freezing and thawing cycling. This was further confirmed by the relatively small changes in weight, length and pulse-velocity measurements recorded over the duration of the test. The apparent loss of strength of the test specimens after 300 cycles of freezing and thawing, as indicated by the residual strength results shown in Tables 23 and 25, was mostly a reflection of the fact that the companion specimens stored under standard moist-curing conditions during the whole test period had achieved much greater maturity at the end of the test period. This also explains the differences in the residual strengths observed for the test specimens exposed to freezing and thawing cycling at the age of 14 days as compared to those at the age of 91 days. In general, the test specimens exhibited some surface scaling at the conclusion of the freezing and thawing cycling. The degree of scaling was comparable to that previously noted for the non-fibre reinforced high-volume fly ash concrete, and typical of what is generally observed with concretes incorporating relatively large quantities of supplementary cementing materials. The scaling was, however, clearly limited to a certain surface layer of the test specimens, and had no effect on the properties of material internally and the integrity of the concrete mass.

Cost Estimates for the Capping System

It is believed that the polypropylene fibre-reinforced cementitious capping system mentioned above can be shotcreted in place at Halifax International Airport at an approximate cost of \$12 per square meter with an average thickness of 50-mm using a fiber loading of 5 kg/m^3. This is based on the following current prices of materials and estimated cost of shotcreting in the area of Halifax:

	\$/Unit	\$/m^2 of Capping
Concrete (High Volume Fly Ash Delivered at the airport site)	90.00/m^3	4.50
Superplasticizer (Naphthalene-based 5 litres/m^3)	3.00/litre	0.75
Fibre (40-mm fibermesh)	7.00/kg	1.75
Shotcreting	5.00/m^2	5.00
	TOTAL	\$12.00

This estimate may vary depending upon the need for the site preparation and features unique to an individual site.

PHASE B OF STUDIES AT CANMET

Scope

In this part of the study a total of eleven 0.06 m^3 concrete mixtures were made. The water-to-(cement + fly ash) ratio (W/(C+FA)) was kept at 0.32 for all the mixtures.

The cement content was also kept relatively constant at about 150 kg per cubic meter with the exception of one mixture for which a cement content of only 76 kg/m^3 was used. The main variables in the mixtures of this part of the study were type, length and content of the fibres. Three different types and four different lengths of fibres were used. In addition, two mixtures were made using a crushed limestone coarse aggregate instead of the natural gravel that was used in all other mixtures of the study. The grading of aggregates of one of these two mixtures was also different from the grading used in the other mixtures. All mixtures were air entrained and superplasticized. The test specimens cast from the mixtures were subjected to the determination of compressive and flexural strengths, modulus of elasticity, flexural toughness and impact resistance. Test specimens from some of the concrete mixtures were also tested for the determination of drying shrinkage and chloride ion-diffusion through concrete.

Concrete Mixtures

The concrete mixtures were made at CANMET between February 1989 and May 1989. The materials used were the same as reported in Phase A of the study with the following exceptions: a) in addition to the pea gravel used in Phase A, crushed limestone with gradings 2 and 3 (Table 2) was also used in this phase; b) in addition to fibre Type A, the following other fibres were used:

Type B:	from Anthes Ltd., it was used in two lengths of 20 and 40 mm.
Type C:	from Fibermesh Company, it was used in two lengths of 20 and 50 mm.

Mixture Proportions

The concrete mixture proportions are given in Table 4. For all the mixtures, the conditioning of aggregates and procedures of mixing were as reported in Phase A of the study.

The water-to-(cement + fly ash) ratio was kept at 0.32 for all the mixtures. All concretes were proportioned with a cement content of 150 kg/m^3 with the exception of mixture no. 29 which was proportioned with a cement content of 75 kg per cubic meter. The fibre content ranged from 2 to 7 kg/m^3 of concrete. Three types of fibre were used: the length of fibre type A was 38 mm; two lengths, 20 and 50 mm of fibre type B were used and similarly, two lengths, 20 and 50 mm of fibre type C were used.

Two mixtures were made using a crushed limestone coarse aggregate. In one of these mixtures, the grading of the aggregate used was grading no. 3, as specified by ACI 506.2-77 instead of grading no. 2 from the same specification, that was used in all other mixtures of the study.

Only one batch was made for each mixture except for mixture no. 19 for which two batches were necessary to obtain sufficient test specimens for determining the mechanical properties and the freezing and thawing resistance of the concretes.

Properties of Fresh Concrete

The properties of the freshly mixed concretes, i.e., slump, unit weight and air content are given in Table 4.

Preparation and Casting of Test Specimens

In general, four 152 x 305-mm cylinders, four 76 x 102 x 406-mm prisms, four 102 x 102 x 381-mm prisms and two 152 x 51-mm disks were made from each mixture. For some mixtures, a number of 102 x 203-mm cylinders and two more 76 x 102 x 406-mm prisms were also made. Generally, one batch was made for each of the mixtures; the only exception was mixture no. 19 for which two batches were made. In this mixture, in addition to the specimens described above, four 76 x 102 x 406-mm prisms were also made.

The 152 x 305-mm cylinders were used for the determination of compressive strength and modulus of elasticity. The 76 x 102 x 406-mm prisms, were used for determining the flexural strength and the drying shrinkage of concrete and also the freezing and thawing resistance of concrete in the case of mixture no. 19. The 102 x 102 x 381-mm prisms were used for the determination of the flexural toughness of concrete.

The 102 x 203-mm cylinders were used for chloride-ion diffusion test and the disks were tested for impact resistance.

The procedures of casting and curing of the specimens were as described in Phase A of the study.

Testing of Specimens

The testing schedule is shown in Table 7. The tests performed were similar to those performed in Phase A. The procedures of testing were the same as described in Phase A.

Test Results and Their Analysis

A summary of the compressive and flexural strengths and the modulus of elasticity is given in Table 10 for ages up to 91 days. Flexural toughness test results of concrete prisms at 14 and 91 days are shown in Tables 13 and 16 respectively. Impact test results are given in Table 18. The chloride-ion diffusion test was performed on mixtures nos. 19, 26 and 28, and the results are shown in Table 19. The drying shrinkage test results are summarized in Table 21. The freezing and thawing tests were performed on test specimens cast from mixture no. 19 after 14 days of moist curing. A summary of the results of the freezing and thawing test, including the durability factor, is given in Table 22. The flexural strengths of the reference prisms and the test prisms after 300 cycles of freezing and thawing are shown in Table 23. The changes in resonant frequency, pulse velocity and weight of the reference prisms and the prisms subjected to freezing and thawing cycling are shown in Tables 27 to 29.

Discussion

Investigations performed in Phase B were designed to provide some additional information concerning the effect of variables such as type, length and content of polypropylene fibre, and other parameters such as type and grading of coarse aggregate on the properties of fresh and hardened concrete. The mixtures were proportioned on the basis of a constant W/(C + FA) of 0.32, and cement and fly ash contents of 150 and 250 kg/m^3, respectively; except in one case (mixture No. 29) where the cement content was set exceptionally low at a value of 75 kg/m^3 while the total cementitious material content remained the same. Whereas a single type and length of the fibre (38-mm Type A) was used throughout Phase A investigations, in this phase two additional types of polypropylene fibre varying in length from 20 to 50 mm were incorporated into the concrete. Further, in addition to the use of natural gravel of a single grading as the coarse aggregate, such as in Phase A, the use of crushed limestone of two different gradings as the coarse aggregate was also investigated in two of the mixtures. The results which are based on a limited number of combinations of the variables investigated, are discussed below.

Slump

The slump was again controlled through the adjustment of the superplasticizer dosage and was maintained between 25 and 110 mm which provided for adequate workability for the various mixtures. The superplasticizer requirement ranged from 2.3 to 7.7 L/m^3 for the different mixtures and, in general, appeared to be affected by both the length and the content of the fibre.

Air-Entrainment

The air content was maintained at a level of 8 ± 1 per cent as in Phase A. There were no problems in achieving this, regardless of the type, length or content of the fibre. This was also true for the concrete mixtures made with crushed limestone aggregate, as well as the mixture containing an excessively high proportion of the fly ash.

Compressive Strength

The compressive strengths in this phase were determined at the ages of 28 and 91 days. The results are shown in Table 10 and, in most instances, they are comparable to those obtained with the mixtures of Phase A having similar proportions.

There was no clear indication of any of the fibre parameters investigated having a major effect on the compressive strength of the concretes at the two ages. The use of crushed limestone coarse aggregate, either with a fine or coarse grading, produced slightly higher strength values than those obtained with most concretes made with natural gravel as the coarse aggregate. As expected, mixture No. 29, with a very low cement content gave considerably lower results, with strength values being less than 50 per cent of those obtained for the other concrete mixtures.

Flexural Strength

Flexural strength was determined at the ages of 14 and 91 days for each mixture, and the average results were again much the same as those obtained with similarly proportioned mixtures of Phase A (Table 10). As noted for the compressive strength, the amount or the characteristics of the fibre used had apparently no significant effect on the flexural strength of the concrete. The crushed limestone aggregate, once again, appeared to contribute, on the average, to slightly higher strength values than the natural gravel aggregate. The use of an excessively low cement content, in spite of maintaining the same quantity of total cementitious material content, reduced the flexural strength by about 50 per cent.

Young's Modulus of Elasticity "E"

The results of the modulus of elasticity "E" at 91 days (Table 10) were closely related to those of the compressive strength at the same age. Therefore, the observations made above with respect to the effect of the variables on the compressive strength, are also relevant for the "E" value.

Flexural Toughness

Flexural toughness indices were determined on test prisms cast from each mixture of this phase at the ages of 14 and 91 days, and the results are shown in Tables 13 and 16. The values of indices I_5, I_{10} and I_{30} and ratios I_{10}/I_5 and I_{30}/I_{10} obtained for the various concretes of this phase were, in most instances, of a similar order as those observed in Phase A. There were, however, some significant differences between the toughness performance of some of the concretes which could likely be attributed to differences in the fibre component of the mixtures. It was particularly apparent that excessively low fibre loadings, such as 3 kg/m^3 or less, contributed to some reduction in the index values as compared to loadings of 5 kg/m^3 or more. Also, concretes incorporating fibres of type A and C generally produced slightly higher index values at both ages than concrete incorporating fibre type B. In the former cases, the length of fibre was not observed to have much influence on the results; however, in the latter case, the use of 20-mm instead of 40-mm length fibre appeared to have some adverse effect. The highest overall index values at both ages were obtained with concrete incorporating type A fibre at a loading of 7 kg/m^3. This suggests that good dispersion of the fibre in the concrete could be achieved at very high loadings with this type of fibre under laboratory mixing conditions.

Impact Resistance

The results of the impact resistance tests carried out on concrete in Phase B are given in Table 18. The results are shown to be somewhat variable and, as mentioned earlier, this is in large part due to the variability of the test. However, it can be seen that there is no indication of specific trends, except with respect to the use of lower fibre loadings such as 2 or 3 kg/m^3 which clearly contributed to relatively lower impact resistance characteristics. Furthermore, concrete incorporating type C fibre of 50-mm in length at a loading of 5 kg/m^3 also yielded considerably lower impact resistance test values. This was in spite of the particularly good flexural toughness performance previously noted for this concrete. These results cannot be explained.

Resistance to Chloride-Ion Diffusion

Chloride-ion diffusion tests were performed on concrete at the age of 28 days for mixtures No. 19, 26 and 28, and additionally at the age of 91 days for mixture No. 19. The data shown in Table 19 indicate that concrete made with type B fibre of 40-mm length had excellent resistance to chloride ion diffusion, with basically no difference observed from the results obtained with concrete made with type A fibre of similar length and tested in Phase A. The test results also show a slightly poorer performance at 28 days of concrete made with fibre type C of 20-mm length used at a dosage rate of 6 kg/m^3. Though no data are available at 91 days, comparison with the results at 28 days for other mixtures suggest that there is possibly a threshold value in the dosage of a given fibre with respect to the resistance of concrete to chloride ion diffusion for cementitious systems such as those investigated.

Drying Shrinkage Strains

Drying shrinkage strain results for this phase are given in Table 21 for periods of drying of up to 224 days. The data obtained indicate that, in general, the type and length of fibre as well as the dosage used had little influence on the total shrinkage strains of the concretes, with the values ranging from 628 to 745 x 10^{-6} for the variables examined. The type of aggregate and the relative proportions of fly ash to cement within the same total cementitious material content also appeared to have no significant effect on the observed drying shrinkage.

Resistance to Freezing and Thawing

Only test prisms cast from mixture No. 19 of this phase were tested for resistance to rapid freezing and thawing cycles (ASTM C 666, Procedure A), using the less favourable condition of only 14 days of moist-curing prior to cycling. The concrete, which contained 5 kg/m^3 of type B fibre of 40-mm length, showed excellent performance with a durability factor of 101 at the end of 300 cycles. Though there is no data to confirm it, it is reasonable to assume that the use of different lengths or dosages of the fibre would not have significantly affected the freezing and thawing durability of the concrete.

PHASE C OF STUDIES AT CANMET

Scope

A total of eight 0.07 m^3 concrete mixtures were made in this part of the study. The water-to-(cement + fly ash) ratio of the mixtures ranged from 0.29 to 0.32. The fibre used was type C with a length of 40 mm. The fibre content ranged from 3 to 6 kg per m^3 of concrete. All mixtures were air entrained and superplasticized. From all concretes, specimens were cast for the determination of compressive and flexural strengths, modulus of elasticity, flexural toughness, impact resistance, chloride ion diffusion and drying shrinkage.

Concrete Mixtures

The concrete mixtures were made at CANMET in December 1989. The materials used were as reported in Phase B of the study.

Mixture Proportions

The concrete mixtures proportions are shown in Table 5. For all mixtures, the conditioning of the aggregates and procedures of mixing were the same as described in Phase A of the study.

The concrete mixtures were made with W/(C+FA) of 0.36, 0.32 and 0.29. All the mixtures were proportioned with a cement content of 150 kg per m^3 of concrete. All the concretes made incorporated fibre type C, 40 mm in length. For the concrete with a W/(C+FA) of 0.32, four fibre contents were used; 3, 4, 5 and 6 kg per m^3. Two fibre contents, 4 and 5 kg per m^3 were used in both the mixtures with W/(C+FA) of 0.36 and 0.29. Only one batch of concrete was made for each mixture.

Properties of Fresh Concrete

The properties of fresh concrete are given in Table 5.

Preparation and Casting of Test Specimens

Four 152 x 305-mm cylinders, six 76 x 102 x 406-mm prisms, four 102 x 102 x 381-mm prisms, four 102 x 203-mm cylinders and two 152 x 51-mm disks were made from each mixture.

The 152 x 305-mm cylinders were used for the determination of compressive strength and modulus of elasticity. The 76 x 102 x 406-mm prisms were used for determining the flexural strength and the drying shrinkage of concrete. The 102 x 102 x 381-mm prisms were used for the determination of the flexural toughness of concrete. The 102 x 203-mm cylinders were tested for chloride-ion diffusion and the disks for impact resistance.

The procedures of casting and curing of the specimens were as described in Phase A of the study.

Testing of Specimens

The testing schedule is shown in Table 8. The tests performed and the procedures of testing were the same as described in the previous parts of the study.

Test Results and Their Analysis

Compressive and flexural strengths and modulus of elasticity are given in Table 11 for ages up to 91 days. Flexural test results of the prisms at 14 and 91 days are shown in Tables 14 and 17, respectively. Impact test results are given in Table 18. The results of the chloride-ion diffusion tests are summarized in Table 19. The data on the drying shrinkage test are not yet available.

Discussion

Slump

The slump of the concrete mixtures ranged from 20 to 135 mm (Table 5). This is slightly out of the specified range of the test program which was 75 ± 25 mm. However, all concrete mixtures had satisfactory workability. Slight adjustments in the superplasticizer would have permitted to obtain the specified slump.

Superplasticizer Requirement

The data, in general, confirm the results of the previous phases. It was found that the superplasticizer dosage requirement was affected by both the total cementitious content and the fibre content of the mixtures. It can be seen from Table 5 that, in general, for the same cementitious content, the superplasticizer dosage increased when the fibre content increased or, for a similar superplasticizer dosage, the slump decreased when the fibre content increased. The data show also that the superplasticizer requirement decreased slightly when the cementitious content of the mixtures increased.

Air Entrainment

The air content of the concrete mixtures ranged from 6.1 to 8.5 per cent. A slight adjustment in the air-entraining admixture dosage would have been needed for the three mixtures that did not meet the requirement for the program which was set at 8 ± 1 per cent.

Compressive Strength

The data on the compressive strength are shown in Table 11. The compressive strengths ranged from 14.3 to 25.8 MPa at 28 days and from 23.1 to 38.5 MPa at 91 days. The concrete mixtures incorporating the lowest cementitious content showed the lowest compressive strength at both ages; these mixtures had also yielded the lowest unit weight values of fresh concrete. Concretes made with the highest cementitious content showed the highest compressive strengths for a given fibre content. The compressive strength of the concrete proportioned with 400 kg/m^3 of cementitious material decreased with an increase in the fibre content of the mixture. These results confirm observations made in Phase A of the study that proper dispersion of the fibre and compaction of concrete may be difficult to achieve with high fibre loadings, particularly with low cementitious contents.

Flexural Strength

The flexural strengths of test prisms tested ranged from 2.2 to 3.0 MPa at 14 days, and from 3.6 to 5.7 at 91 days. In general, the trends observed for the flexural strength at the above ages were similar to those observed for the compressive strength at the same ages. Remarks made for compressive strength about fibre dispersion and compaction of concrete also apply for flexural strength; concrete incorporating high fibre loadings perform better when high cementitious contents are used.

Modulus of Elasticity

The modulus of elasticity values ranged from 28.8 to 33.5 GPa. In general, the results were a function of the compressive strength test values at the same age.

Flexural Toughness

Flexural toughness test results at 14 and 91 days are shown in Tables 14 and 17 respectively. Explanations about the interpretation of the flexural toughness test are given in Phase A of this report.

The index values obtained for the concrete tested at 14 days are indicative of the fairly good toughness properties. The toughness results at 91 days were noticeably lower than those obtained at 14 days in all cases. As mentioned in Phase A, this decrease in the toughness index values with age is largely the result of a considerable higher first crack strength at the latter age. The toughness values at both 14 and 91 days increased with the fibre loading of the mixture. In general, the toughness index values obtained with fibre type C in this phase of the study were inferior to those obtained in Phase A with fibre type A of a similar length, and for same mixture proportions and fibre contents. The difference is more pronounced at the age of 91 days than at 14 days.

Impact Resistance

The impact test results shown in Table 18 indicate that, in general, an increase in the fibre content improves the performance of the concrete. The impact test results of concrete with the lowest cementitious content appear to be slightly inferior to those of concretes made with higher cementitious contents. Meanwhile, the relatively large variations in test results generally associated with the impact test does not allow to establish a relation between the cementitious content and the impact resistance of the concrete.

Resistance to Chloride-Ion Diffusion

The chloride ion diffusion test was performed on test specimens cast from the concrete mixtures at 28 and 91 days, and the results are shown in Table 19.

The results at 91 days (charge in coulombs) can be considered as low to very low for all concretes with the exception of mixtures no. 32 and 33 for which they are moderate. These results indicate that all fibre reinforced high-volume fly ash concretes have good to excellent performance with respect to their resistance to chloride-ion diffusion. The noticeable difference between the test result for concrete mixtures no. 32 and 33 and those of the other concrete mixtures is not explained, and may be attributed to the variability of test results associated with this test method.

CONCLUSIONS: PHASE A, B AND C

The following conclusions can be drawn from the investigations performed in this study.

1. Polypropylene fibre-reinforced high-volume fly ash concrete having satisfactory workability can be produced with available aggregates and fly ash from the Halifax area.
2. A minimum of 400 kg/m^3 of cementitious material (cement + fly ash) appears to be essential for the proper dispersion of the fibres used.
3. The air-entrained concrete developed has satisfactory mechanical properties, adequate resistance to chloride-ion diffusion, excellent resistance to repeated cycles of freezing and thawing, relatively low drying shrinkage and adequate ductility.
4. The type and length of the fibre do not significantly affect the properties of the fresh and hardened concrete. However, it appears that the preferred fibre length is 40 mm (nominal) and the preferred fibre type is A or C.
5. The type and the grading of the coarse aggregate used do not appear to affect significantly the properties of the fresh and hardened concrete.

6. The best overall performance in the laboratory was observed with the following concrete mixture design:

	Approx. Batch quantities (kg/m^3 of concrete)
Cement (Type 10)	150
Fly ash (Type F)	250-300
Coarse aggregate (10-mm pea gravel)	400
Fine Aggregate (natural sand)	1300-1350
Water	130
Polypropylene fibre (38-mm fibrillated)	5
Superplasticizer (Naphthalene-based)	5 L/m^3
Air-entraining admixture (synthetic resin)	275 L/m^3 (Air content of 8%)
Water/(cement + fly ash)	0.32
Slump	100 mm

7. It is believed that the cementitious system developed in this investigation can be used satisfactorily to shotcrete exposed rock outcrops at Halifax International Airport. It is further estimated that the cost of shotcreting (materials and placing) will be of the order of $12 per square meter with a cover thickness of approximately 50 mm. The cost will fluctuate depending upon the amount and type of the fibre used and the pre-engineering work needed to prepare the site for shotcreting.

Table 1 - Physical Properties and Chemical Analyses of Cement and Fly Ash

	Portland Cement* (ASTM Type I)	Fly Ash**
Physical Tests		
Fineness - passing 75 μm %	-	
- passing 45 μm %	85.3	
- Blaine, m^2/kg	373	
Setting time, min.		
- Initial	165	
- Final	290	
Autoclave expansion %	0.11	
Compressive strength of 51-mm Cubes, MPa: 3-day	18.3	
7-day	24.4	
28-day	33.3	
Chemical Analysis		
Silicon dioxide (SiO_2) %	21.95	37.4
Aluminum oxide (Al_2O_3) %	4.13	17.8
Ferric oxide (Fe_2O_3) %	2.88	26.8
Calcium oxide (CaO), total %	61.73	1.46
Calcium oxide (CaO), free %	0.48	-
Magnesium oxide (MgO) %	3.68	0.74
Sulphur trioxide (SO_3) %	2.81	1.22
Sodium oxide (Na_2O) %	0.25	0.77
Potassium oxide (K_2O) %	0.44	2.66
Loss on ignition %	1.47	2.84
Bogue Potential Compounds		
C_3S	42.8	
C_2S	30.7	
C_3A	6.8	
C_4AF	8.8	
Pozzolanic Activity with Portland Cement		
Activity index at 28 days, %		102.0

*Manufacturers' data
**CANMET data

Table 2 - Grading of Aggregates

Sieve Size	Per Cent by Weight Passing Individual Sieves	
	Grading #2*	Grading #3*
19.0 mm	-	100.0
12.5 mm	-	95.0
9.5 mm	100.0	80.0
4.75 mm	77.5	60.0
2.36 mm	60.0	45.0
1.18 mm	45.0	30.0
600 μm	27.5	20.0
300 μm	14.0	11.0
150 μm	6.0	4.0

*From ACI 506.2-77

Table 3 - Mixture Proportions and Properties of Fresh Concrete; Phase A

Mixture Proportions									Properties of Fresh Concrete		
Mixture No.	W/C+FA*	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3**	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	SP$^+$ L/m^3	AEA^{++} mL/m^3	Slump mm	Unit Weight kg/m^3	Air Content %
1	0.36	124	223	0	400	1378	3.6	190	75	2250	8.7
2	0.36	124	223	4	399	1371	4.8	185	40	2250	8.1
3	0.36	123	220	5	392	1350	7.8	215	30	2215	8.0
4	0.36	149	200	0	404	1390	3.4	185	50	2270	8.4
5	0.36	145	194	4	389	1339	5.4	200	65	2195	8.5
6	0.36	145	193	5	387	1332	7.7	245	45	2185	8.2
7	0.32	127	279	0	395	1362	3.0	210	65	2295	7.7
8	0.32	126	277	4	391	1348	4.5	210	110	2280	7.7
9	0.32	125	274	5	387	1332	6.7	250	105	2255	8.1
10	0.32	151	251	0	394	1358	3.6	205	100	2285	8.0
11	0.32	152	251	4	392	1351	5.1	275	105	2280	7.4
12	0.32	151	250	5	390	1341	6.0	285	75	2270	7.3
13	0.29	126	327	0	380	1307	3.4	235	65	2270	7.7
14	0.29	127	328	4	378	1305	4.8	250	100	2275	7.4
15	0.29	126	328	5	377	1298	5.0	280	110	2265	7.9
16	0.29	152	303	0	383	1316	3.9	245	85	2288	7.5
17	0.29	152	304	4	380	1307	4.2	270	55	2280	7.2
18	0.29	151	302	5	376	1299	5.1	295	120	2265	7.8

*Water-to-(cement + fly ash) ratio

**Fibre content: fibre type A, 38 mm

$^+$Superplasticizer

$^{++}$Air entraining agent

Table 4 - Mixture Proportions and Properties of Fresh Concrete; Phase B

Mixture Proportions									Properties of Fresh Concrete		
Mixture No.	W/C+FA*	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3**	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	SP$^+$ L/m^3	AEA^{++} mL/m^3	Slump mm	Unit Weight kg/m^3	Air Content %
19	0.32	150	251	5(1)	391	1342	5.5	215	55	2270	7.2
20	0.32	148	247	6(2)	384	1322	6.0	275	30	2235	8.3
21	0.32	149	249	6(3)	387	1330	4.5	265	25	2250	9.0
22	0.32	148	247	7(2)	381	1317	6.0	220	45	2230	8.5
23	0.32	150	250	7(3)	387	1338	4.3	250	30	2260	8.3
24	0.32	151	252	5(2)	392(6)	1350	4.6	275	45	2280	7.5
25	0.32	149	248	5(2)	687(7)	1030	6.0	270	70	2250	8.2
26	0.32	150	250	6(4)	388	1336	7.0	400	55	2261	7.2
27	0.32	149	248	5(5)	386	1328	7.7	495	110	2249	8.5
28	0.32	150	250	3(2)	390	1345	3.9	325	95	2268	8.2
29	0.32	76	329	2(2)	392	1351	2.3	240	70	2281	7.6

*Water-to-(cement + fly ash) ratio

**Fibre content

$^+$Superplasticizer

$^{++}$Air entraining agent

(1) Fibre type B, 40 mm

(2) Fibre type A, 38 mm

(3) Fibre type B, 20 mm

(4) Fibre type C, 20 mm

(5) Fibre type C, 50 mm

(6) Crushed limestone, grading #2

(7) Crushed limestone, grading #3

Table 5 - Mixture Proportions and Properties of Fresh Concrete; Phase C

Mixture Proportions									Properties of Fresh Concrete		
Mixture No.	W/C+FA*	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3**	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	SP L/m^3	AEA mL/m^3	Slump mm	Unit Weight kg/m^3	Air Content %
30	0.32	154	255	3	398	1370	4.5	270	25	2313	7.4
31	0.32	152	252	4	394	1355	4.0	220	120	2288	7.8
32	0.32	155	256	5	399	1375	5.1	225	45	2325	6.1
33	0.32	151	251	6	389	1343	7.3	295	45	2275	7.5
34	0.36	148	196	4	396	1360	5.2	185	90	2229	8.0
35	0.36	149	198	5	398	1372	5.1	235	20	2249	6.7
36	0.29	152	303	4	380	1304	4.1	265	115	2275	8.5
37	0.29	155	310	5	387	1331	5.0	290	135	2326	6.2

*Water-to-(cement + fly ash) ratio
**Fibre C, 40 mm

Table 6. Testing Schedule for Hardened Concrete: Phase A

Mixtures	Type of Testing	Age of Testing						
		1 d	7 d	14 d	28 d	91 d	365 d	3 y
(All Mixtures)	Compression (ASTM C39)	2 cylinders	2 cylinders		2 cylinders	2 cylinders	2 cylinders	2 cylinders
	Flexure (ASTM C 78)			2 prisms		2 prisms		2 prisms
	Modulus of elasticity (ASTM C 469)					2 cylinders		
	Flexural toughness (ASTM C 1018)			2 prisms		2 prisms		
	Drying shrinkage (ASTM C 157)	Two prisms were exposed to air-drying at 23°C and 50% R.H. after seven days of water-curing						
(Mixtures 1 to 6 and 13 to 18	Impact strength (ACI-544.2R)				2 disks			
(Mixtures 9, 10, 12)	Chloride ion permeability (AASHTO T 277-83)				2 cylinders	2 cylinders		
(Mixtures 3, 6, 15, 18)	Freezing and Thawing (ASTM C 666)	Two prisms each were subjected to repeated cycles of freezing and thawing at the end of 14 and 91 days of moist-curing						

Table 7. Testing Schedule for Hardened Concrete: Phase B

Mixtures	Type of Testing	Age of Testing		
		14 d	28 d	91 d
(All Mixtures)	Compression (ASTM C 39)		2 cylinders	2 cylinders
	Flexure (ASTM C 78)	2 prisms		2 prisms
	Modulus of elasticity (ASTM C 469)			2 cylinders
	Flexural toughness (ASTM C 1018)	2 prisms		2 prisms
	Impact strength (ACI-544.2R)		2 disks	
(Mixtures 19, and 24 to 29)	Drying shrinkage (ASTM C 157)	Two prisms were exposed to air-drying at 23°C and 50% R.H. after seven days of water-curing		
(Mixtures 19, 26 and 28)	Chloride ion permiability (AASHTO T 277-83)		2 cylinders	2 cylinders
(Mixtures 19)	Freezing and thawing (ASTM C 666)	Two prisms were subjected to repeated cycles of freezing and thawing at the end of 14 days of moist-curing		

Table 8. Testing Schedule for Hardened Concrete: Phase C

Mixtures	Type of Testing	Age of Testing		
		14 d	28 d	91 d
(All Mixtures)	Compression (ASTM C 39)		2 cylinders	2 cylinders
	Flexure (ASTM C 78)	2 prisms		2 prisms
	Modulus of elasticity (ASTM C 469)			2 cylinders
	Flexural toughness (ASTM C 1018)	2 prisms		2 prisms
	Impact strength (ACI-544.2R)		2 disks	
	Chloride ion permeability (AASHTO T 277-83)		2 cylinders	2 cylinders
	Drying shrinkage (ASTM C 157)	Two prisms were exposed to air-drying at 23°C and 50% R.H. after 7 days of water-curing		

Table 9 - Summary of Compressive and Flexural Strengths and Modulus of Elasticity; Phase A

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Compressive Strength (MPa)					Flexural Strength (MPa)		Modulus of Elasticity (GPa)
					1d	7d	28d	91d	365d	14d	91d	91d
1	0.36	124	223	0	2.4	8.2	15.3	27.5	44.8	2.1	3.9	30.5
2	0.36	124	223	4	2.4	8.3	14.4	26.9	43.9	2.2	4.1	30.9
3	0.36	123	220	5	0.4	6.7	12.1	20.9	33.9	2.1	3.9	27.1
4	0.36	149	200	0	3.0	11.4	20.9	32.0	49.9	2.6	4.5	32.7
5	0.36	145	194	4	2.4	9.7	15.9	24.8	39.6	2.3	4.0	29.4
6	0.36	145	193	5	1.1	8.8	14.4	23.4	36.5	2.3	4.2	28.2
7	0.32	127	279	0	2.6	9.1	18.9	28.8	40.5	2.1	3.9	29.8
8	0.32	126	277	4	3.1	9.5	18.9	30.6	43.2	2.3	4.7	29.4
9	0.32	125	274	5	1.9	8.3	15.4	23.6	35.9	2.3	3.9	27.4
10	0.32	151	251	0	3.8	11.5	22.9	32.3	47.3	2.6	4.4	31.8
11	0.32	152	251	4	4.5	12.7	21.9	36.3	52.6	2.8	5.2	33.6
12	0.32	151	250	5	3.7	12.0	20.4	33.3	50.2	2.6	4.7	31.2
13	0.29	126	327	0	1.6	9.0	18.4	31.7	46.5	1.9	4.7	28.5
14	0.29	127	328	4	3.0	9.2	17.0	32.7	47.7	2.4	4.1	29.0
15	0.29	126	328	5	2.6	9.7	17.0	32.2	47.3	2.4	4.8	28.4
16	0.29	152	303	0	3.7	12.2	21.7	35.1	49.6	2.8	5.0	31.2
17	0.29	152	304	4	4.5	11.8	20.6	35.4	49.0	2.7	5.0	32.0
18	0.29	151	302	5	3.7	12.5	21.9	38.8	54.8	2.7	5.2	33.8

*Fibre type A, 38 mm

Table 10 - Summary of Compressive and Flexural Strengths and Modulus of Elasticity; Phase B

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Compressive Strength (MPa)		Flexural Strength (MPa)		Modulus of Elasticity (GPa)
					28d	91d	14d	91d	91d
19	0.32	150	251	$5^{(1)}$	19.9	32.0	2.5	5.1	31.0
20	0.32	148	247	$6^{(2)}$	22.8	41.0	3.1	5.6	34.4
21	0.32	149	249	$6^{(3)}$	20.2	35.1	2.9	4.6	32.5
22	0.32	148	247	$7^{(2)}$	18.0	30.8	2.8	4.7	30.1
23	0.32	150	250	$7^{(3)}$	19.4	36.5	2.5	5.3	32.7
24*	0.32	151	252	$5^{(2)}$	22.1	38.6	3.3	5.9	34.9
25**	0.32	149	248	$5^{(2)}$	22.9	39.5	3.2	5.2	35.5
26	0.32	150	250	$6^{(4)}$	18.7	31.4	2.9	4.2	30.2
27	0.32	149	248	$5^{(5)}$	19.9	32.0	2.9	4.8	29.8
28	0.32	150	250	$3^{(2)}$	21.7	35.2	2.8	4.9	31.9
29	0.32	76	329	$2^{(2)}$	9.8	15.9	1.3	2.8	21.1

*Crushed limestone, grading #2
**Crushed limestone, grading #3
(1) Fibre type B, 40 mm
(2) Fibre type A, 38 mm
(3) Fibre type B, 20 mm
(4) Fibre type C, 20 mm
(5) Fibre type C, 50 mm

Table 11 - Compressive and Flexural Strengths and Modulus of Elasticity; Phase C

Mixture No.	W/C+FA*	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3**	Compressive Strength (MPa)		Flexural Strength (MPa)		Modulus o Elasticit (GPa)
					28d	91d	14d	91d	91d
30	0.32	154	255	3	23.4	38.5	2.7	5.4	33.2
31	0.32	152	252	4	20.6	34.4	2.5	4.7	33.5
32	0.32	155	256	5	19.3	30.5	2.7	4.6	30.9
33	0.32	151	251	6	17.0	29.6	2.5	3.6	30.8
34	0.36	148	196	4	14.3	23.1	2.2	4.0	30.4
35	0.36	149	198	5	16.1	25.0	2.4	4.3	28.8
36	0.29	152	303	4	23.8	34.3	2.8	5.1	33.1
37	0.29	155	310	5	25.8	38.1	3.0	5.7	33.2

*Water-to-(cement + fly ash) ratio
**Fibre type C, 40 mm

Table 12 - Flexural Toughness Test Results at 14d; Phase A

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
2	0.36	124	223	4	1.7	3.7	6.9	20.5	1.9	3.0
3	0.36	123	220	5	1.7	4.0	7.6	23.2	1.9	3.1
5	0.36	145	194	4	1.9	4.0	7.7	23.1	1.9	3.0
6	0.36	145	193	5	2.2	3.9	7.6	23.3	1.9	3.1
8	0.32	126	277	4	2.0	3.9	7.5	22.7	1.9	3.0
9	0.32	125	274	5	1.9	3.8	7.3	23.7	1.9	3.2
11	0.32	152	251	4	2.5	3.3	6.0	17.8	1.8	3.0
12	0.32	151	250	5	2.3	3.9	7.5	23.2	1.9	3.1
14	0.29	127	328	4	2.1	3.6	6.9	21.7	1.9	3.1
15	0.29	126	328	5	1.9	3.3	6.2	19.1	1.9	3.1
17	0.29	152	304	4	2.2	3.3	6.3	19.4	1.9	3.1
18	0.29	151	302	5	2.3	3.8	7.3	22.3	1.9	3.1

*Fibre type A, 38 mm

Table 13 - Flexural Toughness Test Results at 14d; Phase B

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
19	0.32	150	251	5$^{(1)}$	2.1	2.9	5.4	15.9	1.9	2.9
20	0.32	148	247	6	2.6	3.9	7.7	23.6	2.0	3.1
21	0.32	149	249	6$^{(2)}$	2.3	3.1	5.6	15.4	1.8	2.8
22	0.32	148	247	7	2.2	4.0	7.7	23.7	1.9	3.1
23	0.32	150	250	7$^{(2)}$	2.0	3.2	6.0	16.7	1.9	2.8
24^{+}	0.32	151	252	5	2.3	3.3	6.1	18.2	1.8	3.0
25^{++}	0.32	149	248	5	2.7	3.4	6.3	17.4	1.9	2.8
26	0.32	150	250	6$^{(3)}$	2.7	3.7	6.8	19.4	1.8	2.9
27	0.32	149	248	5$^{(4)}$	2.5	3.6	6.8	20.0	1.9	2.9
28	0.32	150	250	3	2.4	2.8	4.9	13.4	1.8	2.7
29	0.32	76	329	2	1.1	3.2	5.7	15.4	1.8	2.7

*Fibre type A, 38 mm unless specified

(1) Fibre type B, 40 mm

(2) Fibre type B, 20 mm

(3) Fibre type C, 20 mm

(4) Fibre type C, 50 mm

$^{+}$Crushed limestone coarse aggregate grading #2

$^{++}$Crushed limestone coarse aggregate grading #3

Table 14 - Flexural Toughness Test Results at 14d; Phase C

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
30	0.32	154	255	3	2.4	2.7	4.8	13.2	1.8	2.8
31	0.32	152	252	4	2.0	3.4	6.2	18.2	1.8	2.9
32	0.32	155	256	5	2.4	3.9	7.5	23.4	1.9	3.1
33	0.32	151	251	6	2.2	4.0	7.9	24.8	2.0	3.1
34	0.36	148	196	4	2.1	3.3	6.2	18.7	1.9	3.0
35	0.36	149	198	5	2.2	3.7	7.0	21.6	1.9	3.1
36	0.29	152	303	4	2.6	2.9	5.0	14.2	1.7	2.8
37	0.29	155	310	5	2.5	3.2	5.9	18.2	1.8	3.1

*Fibre type C, 40 mm

Table 15 - Flexural Toughness Test Results at 91d; Phase A

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
2	0.36	124	223	4	4.2	3.1	5.5	14.8	1.8	2.7
3	0.36	123	220	5	3.4	3.3	6.2	17.6	1.9	2.8
5	0.36	145	194	4	3.7	3.0	5.5	15.6	1.8	2.8
6	0.36	145	193	5	3.4	3.4	6.3	18.0	1.9	2.9
8	0.32	126	277	4	3.8	2.7	4.8	13.6	1.8	2.8
9	0.32	125	274	5	3.6	3.3	6.1	17.2	1.8	2.8
11	0.32	152	251	4	4.3	2.6	4.5	11.9	1.7	2.6
12	0.32	151	250	5	4.6	2.8	5.0	13.1	1.8	2.6
14	0.29	127	328	4	4.2	2.7	4.8	13.9	1.8	2.9
15	0.29	126	328	5	4.3	3.1	5.8	17.0	1.9	2.9
17	0.29	152	304	4	4.4	2.2	3.6	8.8	1.6	2.4
18	0.29	151	302	5	4.6	3.2	6.0	17.5	1.9	2.9

*Fibre type A, 40 mm

Table 16 - Flexural Toughness Test Results at 91d; Phase B

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
19	0.32	150	251	5(1)	4.1	2.9	5.2	13.3	1.8	2.6
20	0.32	148	147	6	5.1	3.5	6.7	15.8	1.9	2.4
21	0.32	149	249	6(2)	4.9	2.6	4.5	11.7	1.7	2.6
22	0.32	148	247	7	4.3	4.0	7.5	23.3	1.9	3.1
23	0.32	150	250	7(2)	4.3	2.7	4.8	12.2	1.8	2.5
24+	0.32	151	252	5	4.8	3.6	6.5	18.7	1.8	2.9
25++	0.32	149	248	5	4.7	3.1	5.7	14.2	1.8	2.5
26	0.32	150	250	6(3)	4.1	3.5	6.6	18.5	1.9	2.8
27	0.32	149	248	5(4)	4.1	3.0	5.6	14.9	1.9	2.7
28	0.32	150	250	3	4.1	2.0	3.3	8.5	1.7	2.6
29	0.32	76	329	2	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

*Fibre type A, 38 mm unless specified
(1)Fibre type B, 40 mm
(2)Fibre type B, 20 mm
(3)Fibre type C, 20 mm
(4)Fibre type C, 50 mm
+Crushed limestone coarse aggregate, grading #2
++Crushed limestone coarse aggregate, grading #3
N.A.: Data not available

Table 17 - Flexural Toughness Test Results at 91d; Phase C

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3*	First Crack Strength (MPa)	Toughness Indices			Ratios	
						I_5	I_{10}	I_{30}	I_{10}/I_5	I_{30}/I_{10}
30	0.32	154	255	3	4.1	1.9	3.1	7.5	1.6	2.4
31	0.32	152	252	4	4.2	2.2	3.7	10.6	1.7	2.9
32	0.32	155	256	5	3.4	2.6	4.7	13.4	1.8	2.9
33	0.32	151	251	6	4.2	2.9	5.2	13.5	1.8	2.6
34	0.36	148	196	4	3.7	2.4	4.1	11.4	1.7	2.8
35	0.36	149	198	5	4.0	2.5	4.4	N/A	1.8	N.A.
36	0.29	152	303	4	4.6	2.2	3.7	10.1	1.7	2.7
37	0.29	155	310	5	4.7	2.4	4.1	11.6	1.7	2.8

*Fibre type C, 40 mm

Table 18 - Impact Test Results

Phase	Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Number of Blows	
						First Crack	Ultimate Crack
A	1	0.36	124	223	0	11	12
	2	0.36	124	223	4	16	53
	3	0.36	123	220	5	10	150
	4	0.36	149	200	0	12	13
	5	0.36	145	194	4	13	72
	6	0.36	145	193	5	16	48
	13	0.29	126	327	0	10	11
	14	0.29	127	328	4	9	130
	15	0.29	126	328	5	12	97
	16	0.29	152	303	0	6	8
	17	0.29	152	304	4	6	77
	18	0.29	151	302	5	8	123
B	19	0.32	150	251	5$^{(1)}$	14	121
	20	0.32	148	247	6	9	78
	21	0.32	149	249	6$^{(2)}$	10	83
	22	0.32	148	247	7	17	146
	23	0.32	150	250	7$^{(2)}$	14	116
	24^{+}	0.32	151	252	5	23	108
	25^{++}	0.32	149	248	5	18	62
	26	0.32	150	250	6$^{(3)}$	13	87
	27	0.32	149	248	5$^{(4)}$	13	37
	28	0.32	150	250	3	17	50
	29	0.32	76	329	2	5	30
C	30	0.32	154	255	3$^{(5)}$	13	51
	31	0.32	152	252	4$^{(5)}$	8	96
	32	0.32	155	256	5$^{(5)}$	8	167
	33	0.32	151	251	6$^{(5)}$	17	113
	34	0.36	148	196	4$^{(5)}$	9	70
	35	0.36	149	198	5$^{(5)}$	8	110
	36	0.29	152	303	4$^{(5)}$	6	95
	37	0.29	155	310	5$^{(5)}$	13	143

*Fibre type A, 38 mm unless specified

(1) Fibre type B, 40 mm

(2) Fibre type B, 20 mm

(3) Fibre type C, 20 mm

(4) Fibre type C, 50 mm

(5) Fibre type C, 40 mm

$^{+}$Aggregate grading #2, crushed limestone c.a.

$^{++}$Aggregate grading #3, crushed limestone c.a.

Table 19 - Chloride Ion Diffusion

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Chloride Ion Permeability (Coulombs)	
					28d	91d
9	0.32	125	274	5(1)	3259	383
10	0.32	151	251	0	2546	-
12	0.32	151	250	5(1)	2531	476
19	0.32	150	251	5(2)	2949	555
26	0.32	150	250	6(3)	4873	-
28	0.32	150	250	3(1)	2015	-
30	0.32	154	255	3(4)	1794	459
31	0.32	152	252	4(4)	3509	703
32	0.32	155	256	5(4)	7618	2500
33	0.32	151	251	6(4)	9073	2721
34	0.36	148	196	4(4)	8269	871
35	0.36	149	198	5(4)	7113	936
36	0.29	152	303	4(4)	2269	693
37	0.29	155	310	5(4)	2530	566

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm
(3) Fibre type C, 20 mm
(4) Fibre type C, 40 mm

Table 20 - Summary of Drying Shrinkage Test Results After 7-Day Initial Moist Curing; Phase A

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Shrinkage Strain x 10^{-6}					
					7d	14d	28d	56d	112d	224d
1	0.36	124	223	0	256	426	564	617	667	680
2	0.36	124	223	4	270	489	617	674	710	702
3	0.36	123	220	5	309	479	593	677	702	720
4	0.36	149	200	0	170	333	451	525	603	592
5	0.36	145	194	4	206	397	553	610	646	646
6	0.36	145	193	5	163	323	507	614	695	712
7	0.32	127	279	0	295	412	518	599	631	603
8	0.32	126	277	4	284	390	539	614	656	614
9	0.32	125	274	5	277	451	599	688	720	712
10	0.32	151	251	0	238	394	465	571	624	627
11	0.32	152	251	4	252	447	589	667	716	720
12	0.32	151	250	5	295	475	617	699	734	744
13	0.29	126	327	0	192	422	543	677	695	705
14	0.29	127	328	4	274	362	518	614	713	716
15	0.29	126	328	5	241	422	575	660	712	745
16	0.29	152	303	0	231	369	497	560	628	664
17	0.29	152	304	4	160	362	504	585	634	666
18	0.29	151	302	5	231	387	511	610	656	713

*Fibre type A, 38 mm

Table 21 - Summary of Drying Shrinkage Test Results After 7-Day Initial Moist Curing; Phase B

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Shrinkage Strain x 10^{-6}					
					7d	14d	28d	56d	112d	224d
19	0.32	150	251	5(1)	355	504	617	646	660	674
24[+]	0.32	151	252	5(2)	206	376	542	543	588	663
25[++]	0.32	149	248	5(2)	167	336	472	567	571	652
26	0.32	150	250	6(3)	-	358	567	667	720	745
27	0.32	149	248	5(4)	-	369	570	653	723	742
28	0.32	150	250	3(2)	-	276	472	556	603	639
29	0.32	76	329	2(2)	248	344	461	522	621	628

(1) Fibre type B, 40 mm

(2) Fibre type A, 38 mm

(3) Fibre type C, 20 mm

(4) Fibre type C, 50 mm

[+] Crushed limestone, coarse aggregate, grading #2

[++] Crushed limestone, coarse aggregate, grading #3

Table 22 - Summary of Results After 300 Cycles of Freezing and Thawing for Prisms Moist Cured 14 days

Mixture No.	W/C+FA	Cement kg/m³	Fly Ash kg/m³	Fibre kg/m³	Weight Change %	Length Change %	Pulse Velocity Change, %	Longitudinal Frequency Change, %	Durability Factor
3	0.36	123	220	5(1)	-1.8	+0.03	+2.9	-1.7	97
6	0.36	145	193	5(1)	-0.8	+0.01	+3.5	-0.3	100
15	0.29	126	328	5(1)	-5.5	+0.02	+2.6	-1.4	97
18	0.29	151	302	5(1)	-1.1	+0.00	+4.1	+1.4	103
19	0.32	150	251	5(2)	-1.6	N.A.	+2.0	+0.6	101

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm

Table 23 - Flexural Strengths of Prisms After 300 Cycles of Freezing and Thawing for Prisms Moist Cured 14 days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Reference Prisms		Prisms for Fr/th	
					At 14d (MPa)	At end of Fr/th Cycling (MPa)	At end of Fr/th Cycling (MPa)	Residual Strength %
3	0.36	123	220	5(1)	2.1	4.1	2.1	51.2
6	0.36	145	193	5(1)	2.3	3.6	2.2	61.1
15	0.29	126	328	5(1)	2.4	5.1	2.1	41.2
18	0.29	151	302	5(1)	2.7	5.4	3.2	59.3
19	0.32	150	251	5(2)	2.5	5.2	2.6	50.0

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm

Table 24 - Summary of Results After 300 Cycles of Freezing and Thawing for Prisms Moist Cured 91 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Weight Change %	Pulse Velocity Change, %	Longitudinal Frequency Change, %	Durability Factor
3	0.36	123	220	5	-0.6	-0.9	-2.3	96
6	0.36	145	193	5	+0.3	-0.6	-4.1	92
15	0.29	126	328	5	-0.8	-4.0	-3.6	93
18	0.29	151	302	5	-0.1	0.0	-2.0	96

*Fibre type A, 38 mm

Table 25 - Flexural Strength of Prisms After 300 Cycles of Freezing and Thawing for Prisms Moist Cured 91 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Reference Prisms		Prisms for Fr/Th	
					At 91d (MPa)	At End of Fr/Th Cycling (MPa)	At End of Fr/Th Cycling (MPa)	Residual Strength (MPa)
3	0.36	123	220	5	3.9	4.9	3.7	75.5
6	0.36	145	193	5	4.2	4.6	3.6	78.3
15	0.29	126	328	5	4.8	5.3	4.6	86.8
18	0.29	151	302	5	5.2	6.5	5.5	84.6

*Fibre type A, 38 mm

Table 26 - Changes in Length of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 14 Days

Mixture No.	W/C+FA	Cement kg/m³	Fly Ash kg/m³	Fibre kg/m³	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 14 Days (mm)	At End of Fr/Th Cycling (mm)	Percent Change	At 14 Days (mm)	At End of Fr/Th Cycling (mm)	Percent Change	Relative Change %
3	0.36	123	220	5(1)	364.137	364.128	-0.003	363.853	363.963	+0.030	+0.033
6	0.36	145	193	5(1)	363.568	363.562	-0.002	364.071	364.098	+0.007	+0.009
15	0.29	126	328	5(1)	364.400	364.389	-0.003	363.484	363.524	+0.011	+0.014
18	0.29	151	302	5(1)	364.001	363.981	-0.006	364.380	364.365	-0.004	+0.002
19	0.32	150	251	5(2)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm
N.A.: Data not available

Table 27 - Changes in Fundamental Longitudinal Resonant Frequency of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 14 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 14 Days (Hz)	At End of Fr/Th Cycling (Hz)	Percent Change	At 14 Days (Hz)	At End of Fr/Th Cycling (Hz)	Percent Change	Relative Change %
3	0.36	123	220	5$^{(1)}$	4475	4850	+8.4	4500	4425	-1.7	-10.1
6	0.36	145	193	5$^{(1)}$	4475	4800	+7.3	4475	4463	-0.3	-7.6
15	0.29	126	328	5$^{(1)}$	4475	4900	+9.5	4475	4415	-1.3	-10.8
18	0.29	151	302	5$^{(1)}$	4588	5025	+9.5	4638	4700	+1.3	-8.2
19	0.32	150	251	5$^{(2)}$	4625	5100	+10.1	4600	4625	+0.5	-9.6

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm

Table 28 - Changes in Ultrasonic Pulse Velocity of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 14 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre kg/m^3	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 14 Days (m/s)	At End of Fr/Th Cycling (m/s)	Percent Change	At 14 Days (m/s)	At End of Fr/Th Cycling (m/s)	Percent Change	Relative Change %
3	0.36	123	220	5(1)	3935	4241	+7.8	3998	4112	+2.9	-4.9
6	0.36	145	193	5(1)	3949	4234	+7.2	3943	4078	+3.4	-3.8
15	0.29	126	328	5(1)	4021	4372	+8.7	4042	4143	+2.5	-6.2
18	0.29	151	302	5(1)	4095	4458	+8.9	4145	4316	+4.1	-4.8
19	0.32	150	251	5(2)	4069	4427	+8.8	4065	4143	+1.9	-6.9

(1)Fibre type A, 38 mm
(2)Fibre type B, 40 mm

Table 29 - Changes in Weight of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 14 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 14 Days (kg)	At End of Fr/Th Cycling (kg)	Percent Change	At 14 Days (kg)	At End of Fr/Th Cycling (kg)	Percent Change	Relative Change %
3	0.36	123	220	5(1)	6877	6925	+0.7	6924	6803	-1.7	-2.4
6	0.36	145	193	5(1)	6818	6820	0	6771	6718	-0.8	-0.8
15	0.29	126	328	5(1)	7046	7063	+0.2	6980	6600	-5.4	-5.6
18	0.29	151	302	5(1)	7047	7093	+0.7	7099	7023	-1.1	-1.8
19	0.32	150	251	5(2)	7068	7083	+0.2	6983	6870	-1.6	-1.8

(1) Fibre type A, 38 mm
(2) Fibre type B, 40 mm

Table 30 - Changes in Fundamental Longitudinal Resonant Frequency of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 91 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 91 Days (Hz)	At End of Fr/Th Cycling (Hz)	Percent Change	At 91 Days (Hz)	At End of Fr/Th Cycling (Hz)	Percent Change	Relative Change %
3	0.36	123	220	5	4975	5025	+1.0	4938	4825	-2.3	-3.3
6	0.36	145	193	5	4963	5025	+1.2	4950	4750	-4.0	-5.2
15	0.29	126	328	5	4938	5000	+1.3	4950	4775	-3.5	-4.8
18	0.29	151	302	5	5100	5125	+0.5	5100	5100	-2.0	-2.5

*Fibre type A, 38 mm

Table 31 - Changes in Ultrasonic Pulse Velocity of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 91 Days

Mixture No.	W/C+FA	Cement kg/m^3	Fly Ash kg/m^3	Fibre* kg/m^3	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 91 days (m/s)	At End of Fr/Th Cycling (m/s)	Percent Change	At 91 Days (m/s)	At End of Fr/Th Cycling (m/s)	Percent Change	Relative Change %
3	0.36	123	220	5	4392	4430	+0.9	4345	4306	-0.9	-1.8
6	0.36	145	193	5	4297	4390	+2.2	4255	4229	-0.6	-2.8
15	0.29	126	328	5	4350	4422	+1.7	4390	4215	-4.0	-5.7
18	0.29	151	302	5	4536	4560	+0.5	4512	4512	0	-0.5

*Fibre type A, 38 mm

Table 32 - Changes in Weight of Test Prisms During Freezing and Thawing Cycling; for Prisms Moist Cured 91 Days

Mixture No.	W/C+FA	Cement kg/m³	Fly Ash kg/m³	Fibre* kg/m³	Reference Moist Cured Prisms			Freeze-Thaw Test Prisms			
					At 91 Days (kg)	At End of Fr/Th Cycling (kg)	Percent Change	At 91 Days (kg)	At End of Fr/Th Cycling (kg)	Percent Change	Relative Change %
3	0.36	123	220	5	6938	6948	+0.1	6880	6840	-0.6	-0.7
6	0.36	145	193	5	6873	6903	+0.4	6815	6835	+0.3	-0.1
15	0.29	126	328	5	7040	7045	+0.1	7048	6995	-0.8	-0.9
18	0.29	151	302	5	7130	7135	+0.1	7080	7075	-0.1	-0.2

*Fibre type A, 38 mm

PART II: INVESTIGATIONS PERFORMED BY HARDY BBT LTD., VANCOUVER

The scope of work to be performed by Hardy BBT Ltd., Vancouver, was as follows:

Scope of Work

Phase I

To perform laboratory studies to support investigations performed at CANMET, and to conduct additional studies to optimize cementitious content, fibre content and superplasticizer dosage.

Phase II

Utilizing the optimized mixture proportions in Phase I, to fabricate small and large shotcrete panels using full-scale shotcrete production procedures and to determine the mechanical properties, shrinkage, cracking characteristics and durability of the shotcrete.

Results of Investigations

The detailed results of the above investigations together with conclusions are included in this document as Annexes 1 and 2.

PART III: INVESTIGATIONS PERFORMED BY COMRIE CONSULTANTS LTD., TORONTO

The scope of work to be performed by Comrie consultants Ltd., Toronto was as follows:

Scope of Work

To develop geopolymers formulations for capping pyritic slate outcrops at the Halifax International Airport. The formulations will be developed with a view of optimizing the use of geopolymers and other mineral admixtures such as fly ash, slag and silica fume. Data on mechanical properties such as compression, flexural and modulus of elasticity will be developed. Additional test specimens will be cast and will be shipped to the CANMET laboratories where determinations of freezing and thawing resistance, permeability and coefficient of thermal expansion of these geopolymer systems will be performed. Large panels will be shotcreted to test the applicability of the geopolymers using a shotcrete gun. The panels will be cored to determine the mechanical properties of the material. Data obtained in the above investigation will be analyzed as to determine the feasibility of using the geopolymer technology for capping the pyritic slate outcrops, and cost estimates of doing such a job will be given.

Results of Investigations

The detailed results of the above investigations are included in this document as Annex 3.

OVERALL CONCLUSIONS: PART I, II AND III

1. CANMET investigations have shown that polypropylene fibre-reinforced high-volume fly ash concrete can be produced with satisfactory engineering properties.
2. Investigations performed by Hardy BBT Ltd., Vancouver, have confirmed the results obtained at CANMET. Further, the Company has demonstrated that the above developed concrete can be properly shotcreted using conventional wet shotcreting equipment.
3. Based upon the work performed at CANMET and at Hardy BBT Ltd. and after consultation with shotcrete industry representatives, it is believed that the above concrete can be shotcreted in place at Halifax International Airport at a cost of approximately $12 per square meter with an average thickness of 50 mm. The cost may vary depending upon the needs of pre-engineering required for site preparation.
4. Investigations performed by Comrie Ltd., Toronto on geopolymer systems have yielded limited test data only and do not allow any satisfactory conclusions to be drawn as to their field applications.

RECOMMENDATIONS

In view of the above conclusions, it is recommended that the polypropylene fibre-reinforced, high-volume fly ash shotcrete system developed under this research program be given serious consideration for capping pyritic rock outcrops at the Halifax International Airport.

Based on the results of both the laboratory investigations by CANMET and the field performance tests by Hardy BBT Ltd., the recommended concrete mixture design range for the system is as follows:

	Batch quantities (kg/m^3 of concrete
Cement (Type 10)	150-170
Fly Ash (Type F)	250-300
Coarse aggregate (10-mm pea gravel)	400-450
Fine aggregate (natural sand)	1250-1350
Water	130-145
Polypropylene fibre (38-mm fibrillated)	4-5
Water-reducing admixture	(optional use)
Superplasticizer (Naphthalene-based)	as required for slump (est. 4-7 L/m^3)
Air-entraining admixture	as required for 5 ± 1% air content after shotcreting
Water/(cement + fly ash	0.30-0.40
Slump	as required for shotcreting (est. 100 ± 25 mm)

ANNEX-1

REPORT ON PHASE I INVESTIGATIONS BY HARDY BBT LTD.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PHASE I REPORT ON
DEVELOPMENT AND EVALUATION OF CEMENT/FLY ASH - BASED SEALANTS FOR CAPPING PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

PREPARED FOR
SCIENCE & PROFESSIONAL SERVICES DIRECTORATE
SUPPLY AND SERVICES CANADA
HULL, QUEBEC

CONTRACT NO. 23440-8-9164/01-SQ
SCC FILE NO. 015SQ.23440-8-9164

BY
HARDY BBT LIMITED
VANCOUVER, B.C.

VA-01584
October 19, 1989

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APPENDIX A:

Table 1: Portland Cement Properties
Table 2: Fly Ash Properties
Technical Report #1: 10 mm Aggregate Gradation
Technical Report #2: Sand Gradation
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Technical Report #4: Plain Control Mixture Proportions
Technical Report #5: 60% Fly Ash Mixture Proportions
Technical Report #6: 75% Fly Ash Mixture Proportions
Technical Report #7: Plain Control Mixture: Hardened Properties
Technical Report #8: 60% Fly Ash Mixture: Hardened Properties
Technical Report #9: 75% Fly Ash Mixture: Hardened Properties
Technical Report #10: Phase II Study: Recommended Mixture Proportions

APPENDIX B:

Product Literature, "Durasar" Superplasticizer
Product Literature, "Forta CR" Fibres
Load-Deflection Plots

1.0 INTRODUCTION

The terms of reference for this study were set out in the Supply and Services Canada Contract No. 23440-8-9164/01-SQ. This report presents the results of the Phase I study. The Phase I study is now complete, except that 56 day compressive strength test data is not yet available; this data will be reported as soon as completed.

The Phase I study involved mixture optimization studies, based on laboratory casting and testing of various specimens. The main variables specified in the contract were: Fly Ash Content: 0, 60 and 75 percent of total cementitious content of 400 kg/m^3. Polypropylene Fibre Content: 0, 2, 4 and 6 kg/m^3 (where possible). These mix variables were selected to complement a study being conducted by CANMET.

The Phase I work required the laboratory casting of 12 mixtures, from which cylinder and prism specimens were fabricated for the following tests:

- compressive strength on cast 100 mm diameter x 200 mm cylinders at 7, 28 and 56 days;
- flexural strength of cut 75 x 75 x 355 mm prisms at 28 days;
- ASTM C1018 I_5, I_{10} and I_{20} toughness index at 28 days on fibre reinforced mixes.

2.0 SHOTCRETE MATERIALS

2.1 PORTLAND CEMENT

The Portland cement used in this study was supplied by St. Lawrance Cement from Beauport, Quebec and conformed to the requirements of CAN/CSA-A5-M88 for a type 10 Portland cement. Typical physical and chemical properties of the cement are given in Table 1.

2.2 FLY ASH

A low calcium CAN/CSA-A23.5-M86 type F fly ash was used in this study. The ash is collected from a thermal generation plant in Lingan, Nova Scotia and marketed for use in concrete. The ash was supplied by Nova Scotia Sand & Gravel. Typical physical and chemical properties of the fly ash are given in Table 2.

2.3 AGGREGATES

The aggregates used in this study were supplied by Target Products Ltd. of Burnaby, British Columbia. These aggregates are routinely used in shotcrete production in Western Canada. Gradation analyses for the 10 mm coarse aggregate fraction, and shotcrete sand are given in the appended Technical Reports #1 and #2 respectively. The aggregate was combined in a nominal 25:75 coarse aggregate:sand blend by mass. This combined aggregate gradation is compared with the ACI 506R-85, Table 2.1, Gradation No. 2 gradation envelope in the appended Technical Report #3. The combined blend falls on the fine side of the ACI 506.2 gradation envelope on the 1.25 mm and 630 um sieves, but this is viewed as desirable for high volume polypropylene fibre reinforced shotcretes.

2.4 SUPERPLASTICIZER

The superplasticizer used was "DURASAR" supplied by Handy Chemicals Ltd. of La Prairie, Quebec. It is a napthalene sulfonate calcium salt. Product literature for this superplasticizer, together with typical property data is appended to this report. The superplasticizer was added to the base (non-fibre reinforced) shotcretes at dosage rates varying between 0.825 and 1.0 1/100 kg cementitious material. In the fibre reinforced mixtures the dosage rate was increased to a maximum of 2.0 1/100 kg cementious material. Note that the recommended range of addition in the DURASAR product literature is 0.5 to 2.0 1/100 kg cement. DURASAR is understood to conform to the requirements of CAN3-A266.6-M85 Superplasticizing Admixtures for Concrete. No water reducing or air entraining admixtures were used.

2.5 POLYPROPYLENE FIBRE

The fibre used in this study was 38 mm long FORTA CR twisted, fibrillated, polypropylene fibre, supplied by Elsro Construction Products, St. Albert, Alberta. The fibre is manufactured by the Forta Corporation of Grove City, Pennsylvania, U.S.A. Product literature is appended to this report.

3.0 SHOTCRETE MIXES

Three basic shotcrete mixtures were studied:

1. A plain control Portland cement shotcrete, with no fly ash and a nominal 400 kg/m^3 cement content.

2. A mix with 60 percent by mass fly ash and 40 percent by mass Portland cement, with a nominal total cementitious content of 400 kg/m^3.

3. A mix with 75 percent by mass fly ash and 25 percent by mass Portland cement, with a nominal total cementitious content of 400 kg/m^3.

Each of these mixtures was batched with sufficient superplasticizer to provide a workability judged suitable for placement by shotcreting. Initially it was intended to add the polypropylene fibre to the three basic shotcrete mixtures at nominal addition rates of 2, 4 and 6 kg/m^3. These addition rates were achieved with the fly ash mixtures, but in the plain Portland cement mixture it was found that 4 kg/m^3 of polypropylene fibre was the maximum amount which could be added; it was considered that addition of more fibre to this mixture would have resulted in an excessive tendency to bleeding, segregation and fibre matting. Consequently a third mixture was tested at an addition rate of 3 kg/m^3 in the plain Portland cement mix series.

Details of all the as-batched fibre reinforced shotcrete mixture proportions in kg/m^3 (based on SSD aggregates) are given in the appended Technical Reports No. 4, 5 and 6.

4.0 PROPERTIES OF FRESH SHOTCRETE

The following fresh shotcrete properties were determined:

- slump before fibre addition
- slump after fibre addition
- air content
- plastic density

Test results for the plain control (no fly ash) mixtures (Series A mixtures) are given in the appended Technical Report #4. Test results for the 60 percent fly ash mixtures (Series B mixtures) are given in Technical Report #5. Test results for the 75 percent fly ash mixtures (Series C mixtures) are given in Technical Report #6.

A nominal dosage of approximately 4 l/m^3 of superplasticizer was first added with about three quarters of the mixing water to all the base mixtures. The remaining mixing water was then added to bring the slump in to the range of 90 ± 20 mm (with the exception of Mix C4 which had a slump of 130 mm). The polypropylene fibres were added to the various mixtures at the indicated addition rates, together with sufficient superplasticizer to produce a workability judged suitable for shotcreting. No additional water was added during this phase. The shotcrete was mixed for 5 minutes after all fibre and superplasticizer addition and the indicated fresh shotcrete test was then performed.

The general characteristics of the fresh shotcrete were also noted. The Series B fibre reinforced shotcretes with 60 percent fly ash displayed the most desirable plastic characteristics. There was little tendency to bleeding or segregation or fibre matting, in these mixtures, even at fibre addition rates of 6 kg/m^3. By contrast, the plain Portland cement Series A mixtures displayed significant bleeding. At fibre addition rates of 4 kg/m^3 the Mix A3 showed a tendency to segregation and fibre matting and was judged unsuitable for shotcreting. The Series C fibre reinforced shotcretes displayed plastic characteristics intermediate between those displayed by the A and B Mixes; i.e. the C Series mixtures did not appear as cohesive and free of bleeding or segregation as the B Series mixtures, but were noticeably superior to the A series mixtures. It was possible to add up to 6 kg/m^3 of polypropylene fibre to the C Series mixtures, but at this addition rate the shotcrete was judged to be of marginal suitability for use in shotcreting applications.

No air entraining admixture was added to any of the mixtures, but it was noted that air contents in the mixtures varied as follows:

A - Series: 5.9 to 8.0 percent
B - Series: 5.3 to 6.4 percent
C - Series: 3.8 to 5.8 percent

i.e.; the air content tended to reduce with increasing fly ash content. Also, there was a tendency to reducing air content with increasing polypropylene fibre content. The reason for these high air contents in these non-air entrained concretes is not clear, but is likely related to the particular combination of superplasticizer and cementitious materials used. In the Phase II work it is planned to add an air entraining admixture to the shotcrete in the transit mixer since it is expected that as much as half of the air content in the plastic shotcrete will be lost in the shooting process. For reasons of freeze/thaw durability, plastic air contents of 7 ± 1 percent are viewed as desirable for the in place shotcrete.

5.0 PROPERTIES OF HARDENED SHOTCRETE

5.1 COMPRESSIVE AND FLEXURAL STRENGTHS

The values for compressive and flexural strength at 7 and 28 days for the mix Series A, B and C are given in the appended Technical Reports No. 7, 8 and 9 respectively. Given that the water demands and air contents for each of the series were fairly consistent within each series (with the exception of Mix C3) it would be expected that the compressive and flexural strengths should be similar. This was observed to be the case, as the compressive and flexural strengths in each of the series vary over a narrow range. This is encouraging, as it means that with the judicious use of superplasticizer, compressive and flexural strengths can be maintained, even at high volume (up to 6 kg/m^3) polypropylene fibre addition rates.

As expected, the plain Portland cement (Mix Series A) displayed higher 7 and 28 day compressive strengths than the 60 percent fly (Mix Series B) or 75 percent fly ash (Mix Series C) mixtures. 56 day test results will be reported when available. (See note below).

5.2 TOUGHNESS INDEX

All the fibre reinforced shotcrete mixtures were tested at 8 days for toughness index and residual strength in accordance with the ASTM C1018 test procedures. Tests were conducted on 75 x 75 x 355 mm prisms diamond sawcut from panels. Test results are given in the appended Technical Reports No. 7, 8 and 9 for the mixture Series A, B and C respectively. Load vs deflection plots for individual specimens are also attached.

Note: Updated data are given in Appendix C.

A common toughness index specification for fibre reinforced shotcretes used in tunnelling, mining, slope stabilization and remedial shotcrete works is:

$I_5 \geq 3.5$
$I_{10} \geq 5.0$

It can be seen that all the fly ash mixtures with > 4 kg/m^3 of 38 mm Forta CR polypropylene fibre met this performance requirement. At 2 kg/m^3 fibre addition rates the toughness index values for all mixtures were substantially below the above limits. It is suggested that for practical field applications of high volume fly ash shotcretes, the minimum polypropylene fibre addition rate should be at least 4 kg/m^3.

6.0 RECOMMENDATIONS

Based on:

a) the performance of the plastic and hardened properties of shotcretes evaluated in this Phase I study, and

b) review of the data in the complementary study conducted by CANMET and published in the paper "Fibre-Reinforced High-Volume Fly Ash Shotcrete for Controlling Aggressive Leachates from Exposed Rock Surfaces and Mine Tailings", by V.M. Malhotra, G.G. Carette and A. Bilodeau, presented at the Third CANMET/ACI International Conference on Superplasticizers and other Chemical Admixtures in Concrete, Ottawa, October, 1989.

It is recommended that the mixture proportions given in the appended Technical Report #10 be adopted for use in the Phase II field shotcrete study of this contract. Solid volume calculations for each of these mixtures are appended. The Mixes U, V and W have a fly ash + cement content of 400 kg/m^3. The Mixes X, Y and Z are richer, having a fly ash + cement content of 450 kg/m^3.

Based on observations of the characteristics of the plastic Phase I mixtures it is considered undesirable to reduce the total cement + fly ash content below 400 kg/m^3 for practical high volume polypropylene fibre reinforced wet mix shotcretes.

The polypropylene fibre addition rates recommended for study are 3 and 6 kg/m^3. It is considered that these fibre addition rates cover the range of interest. In particular, it will be of interest to note the relative performance in restrained shrinkage tests between the mixtures with 3 and 6 kg/m^3 of polypropylene fibre.

Respectfully submitted,

Hardy BBT Limited,

Per: D. R. Morgan

D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer.

Reviewed by:

A.J. Kirkness, P. Eng.,
Manager - Materials Engineering Division.

DRM:nmd
Enclosures

VA-01584
89-10-19

APPENDIX A

PHASE I INVESTIGATIONS - HARDY BBT LTD.

TABLE 2 - CHEMICAL AND PHYSICAL PROPERTIES OF LINGAN LOW CALCIUM FLY ASH

CHEMICAL COMPOSITION	PERCENT BY MASS
SiO_2	45.2
Al_2O_3	20.7
Fe_2O_3	24.8
CaO	1.63
MgO	0.97
TiO_2	1.05
SO_3	0.65
K_2O	2.40
Na_2O	0.59
PHYSICAL TESTS	**TEST RESULTS**
Loss on Ignition (%)	2.66
Pozzolanic Activity Index (with cement) (%)	97
Blaine Fineness (m^2/kg)	351
Percent Finer Than 45 um	84
Relative Density	2.64

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #1

SIEVE ANALYSIS REPORT

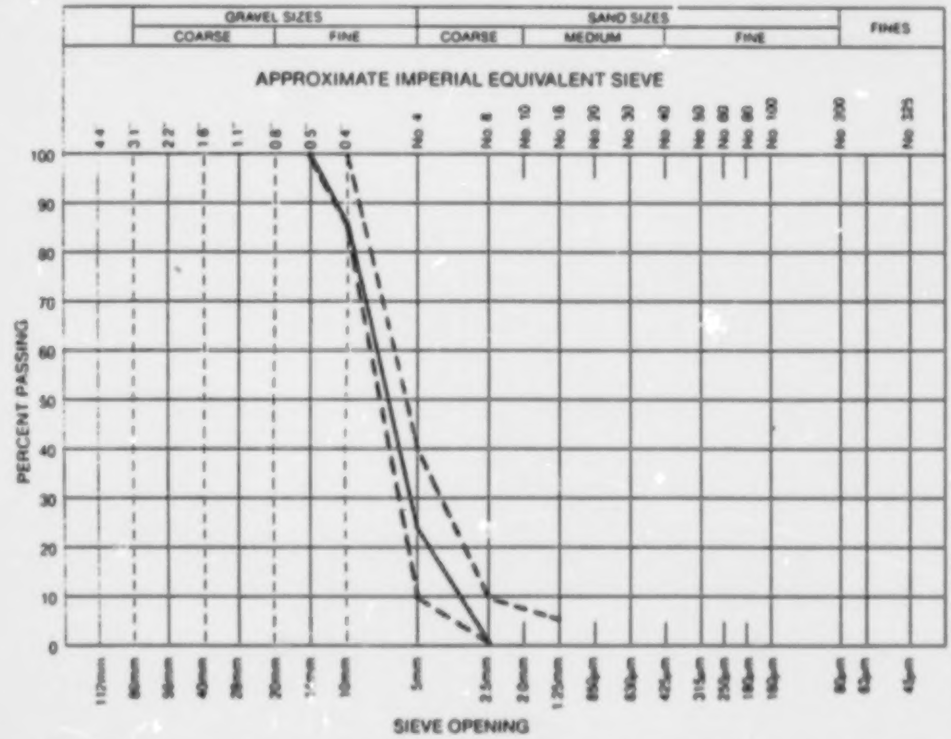
TO:
SCIENCE & PROFESSIONAL SERVICES DIR.
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. W. John Humphries

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE 10 mm Aggregate
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	86.6
No. 4	24.4
No. 8	0.4

SAMPLE DESCRIPTION: 10 mm shotcrete aggregate from Target Products Ltd., Burnaby, B.C.

COMMENTS 10 mm Shotcrete Aggregate Plotted vs CAN3-A23.1-M77, Table 3; Group I
10 - 2.5 mm Envelope

Hardy BBT Limite
Per D. K. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written reque

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #2

SIEVE ANALYSIS REPORT

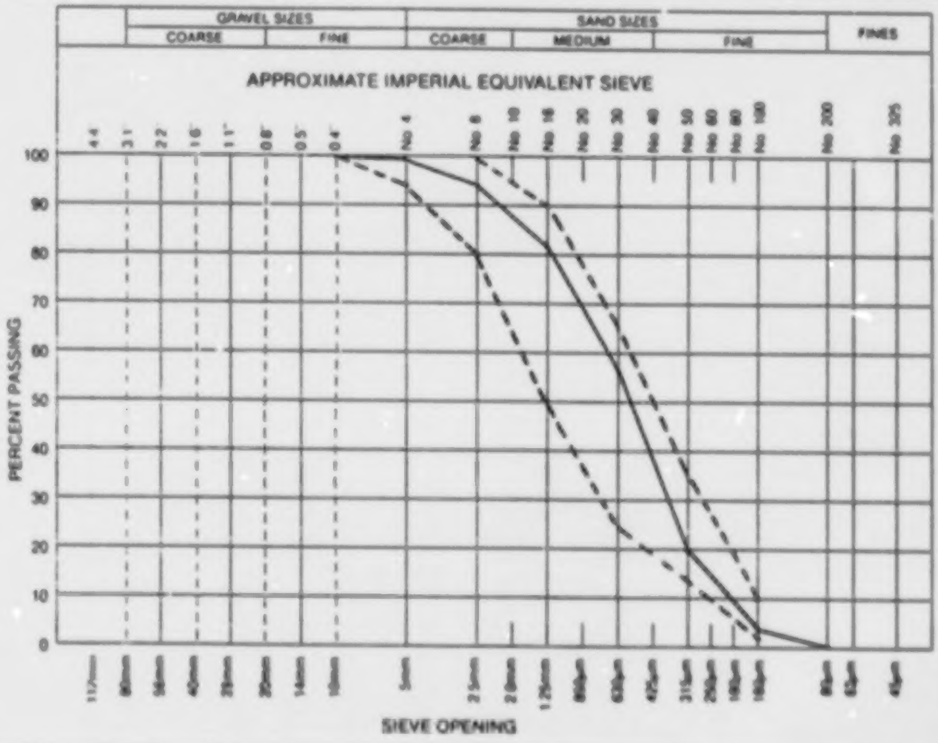
TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. W. John Humphries

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE Sand
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
3/8"	100.0
No. 4	99.1
No. 8	93.8
No. 16	89.1
No. 30	56.7
No. 50	19.6
No.100	3.4
No.200	0.5

SAMPLE DESCRIPTION: Shotcrete sand from Target Products Ltd., Burnaby, B.C.

COMMENTS Sand Gradation Plotted vs. CAN3-A23.1-M77, Table 1 Fine Aggregate Gradation Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIEVE ANALYSIS REPORT

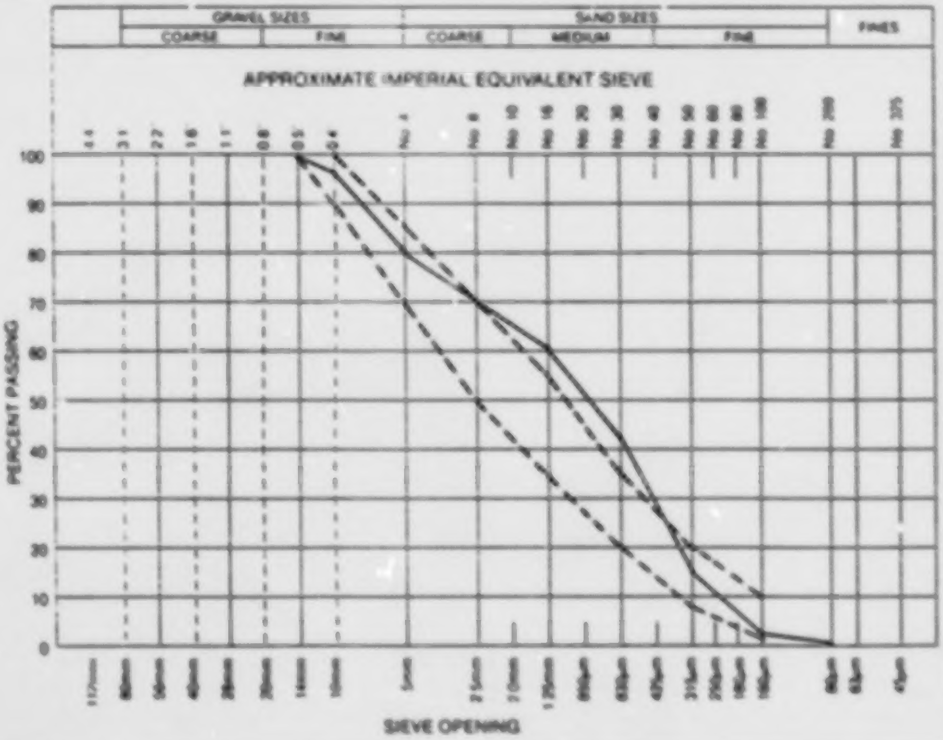
TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. W. John Humphries

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE Combined
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	96.7
No. 4	80.4
No. 8	70.8
No. 16	61.4
No. 30	42.5
No. 50	14.7
No. 100	2.6
No. 200	0.4

SAMPLE DESCRIPTION: Combined blend of 75:25 :: Sand:10 mm Coarse Aggregate by Mass

COMMENTS Combined Blend Shown vs. ACI 506R-85 Table 2.2.1 Gradation No.2 Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #4

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

VA-01584
89-09-28

ATTENTION: Mr. John Humphries

SHOTCRETE STUDY - HALIFAX AIRPORT.
LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.

MIX DESIGNATION: A - Plain Control - No Fly Ash

MIX NO.	A1	A2	A3	A4
Fibre Dosage, kg/m^3	--	2.00	4.00	3.00
Type 10 Cement, kg/m^3	393	391	397	397
Fly Ash, kg/m^3	--	--	--	--
10 x 5 mm Coarse Aggregate, kg/m^3	423	420	427	427
Sand (SSD), kg/m^3	1268	1260	1280	1281
Water (Actual), kg/m^3	157	156	163	163
Superplasticizer, l/m^3	3.96	4.63	8.00	7.00
W/C + FA Ratio	0.40	0.40	0.41	0.41
Slump Before Fibre Addition, mm	70	75	85	90
Slump After Fibre Addition, mm	--	70	40	70
Air Content, %	8.0	8.3	5.9	6.0
Plastic Density, kg/m^3	2234	2225	2250	2258

COMMENTS: 1) Nominal superplasticizer dosage of 4 l/m^3 was added to the base mix prior to fibre adition. Additional superplasticizer was added to the fibre mix to achieve required workability.

2) 38 mm Forta CR Polypropylene fibre was used in this study.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #5

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

VA-01584
89-09-28

ATTENTION: Mr. John Humphries

SHOTCRETE STUDY - HALIFAX AIRPORT.
LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.

MIX DESIGNATION: B - 60% Fly Ash

MIX NO.	B1	B2	B3	B4
Fibre Dosage, kg/m^3	--	2.00	4.05	5.94
Type 10 Cement, kg/m^3	160	161	161	157
Fly Ash, kg/m^3	240	241	241	236
10 x 5 mm Coarse Aggregate, kg/m^3	410	413	412	403
Sand (SSD), kg/m^3	1250	1258	1257	1230
Water (Actual), kg/m^3	150	151	151	162
Superplasticizer, l/m^3	3.30	3.76	4.90	7.29
W/C + FA Ratio	0.38	0.38	0.38	0.41
Slump Before Fibre Addition, mm	110	110	110	85
Slump After Fibre Addition, mm	--	80	100	95
Air Content, %	6.4	5.6	5.3	5.5
Plastic Density, kg/m^3	2251	2276	2270	2251

COMMENTS:
1) Nominal superplasticizer dosage of 4 l/m^3 was added to the base mix prior to fibre adition. Additional superplasticizer was added to the fibre mix to achieve required workability.
2) 38 mm Forta CR Polypropylene fibre was used in this study.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D. R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #6

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

VA-01584
89-09-28

ATTENTION: Mr. John Humphries

SHOTCRETE STUDY - HALIFAX AIRPORT.
LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.

MIX DESIGNATION: C - 75% Fly Ash

MIX NO.	C1	C2	C3	C4
Fibre Dosage, kg/m^3	--	2.00	3.98	6.11
Type 10 Cement, kg/m^3	101	101	99	102
Fly Ash, kg/m^3	302	304	297	305
10 x 5 mm Coarse Aggregate, kg/m^3	412	415	406	417
Sand (SSD), kg/m^3	1257	1266	1218	1257
Water (Actual), kg/m^3	143	135	166	149
Superplasticizer, l/m^3	3.75	5.08	6.11	8.15
W/C + FA Ratio	0.36	0.33	0.42	0.37
Slump Before Fibre Addition, mm	75	70	95	130
Slump After Fibre Addition, mm	--	85	135	90
Air Content, %	5.8	5.7	4.8	3.8
Plastic Density, kg/m^3	2274	2274	2270	2332

COMMENTS:
1) Nominal superplasticizer dosage of 4 l/m^3 was added to the base mix prior to fibre adition. Additional superplasticizer was added to the fibre mix to achieve required workability.
2) 38 mm Forta CR Polypropylene fibre was used in this study.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D. R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #7

TO: SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-10-17
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: A - Plain Control - No Fly Ash

MIX NO.	A1	AVG.	A2	AVG.	A3	AVG.	A4	AVG.
Compressive Strength, MPa								
@ 7 days	36.1, 36.1	36.7	38.4, 37.3	37.9	36.6, 38.2	37.4	34.7, 36.0	35.4
@ 28 days	44.2, 45.9	45.0	46.6, 47.1	46.9	47.4, 48.6	48.3	47.9, 48.6	48.3
@ 56 days								
Flexural Strength, MPa								
@ 28 days	5.3,5.9,5.5	5.6	6.3,6.0,6.0	6.1	5.2,5.2,5.1	5.2	5.4,5.2,5.5	5.4
Toughness Index @ 28 days								
I_5	-	-	2.4,2.2,2.3	2.3	3.2,3.1,3.2	3.2	3.1,3.0,2.9	3.0
I_{10}	-	-	3.6,3.0,3.2	3.3	5.9,5.4,6.2	5.8	5.7,4.9,4.3	5.0
I_{20}	-	-	5.7,4.4,5.1	5.1	10.6, 9.6 11.3	10.5	9.8,8.4,7.0	8.4
Residual Strength, %								
$RS(I_5, I_{10})$	-	-	24, 16, 18	19	54, 46, 60	53	52, 38, 28	39
$RS(I_{10}, I_{20})$	-	-	21, 14, 19	18	47, 42, 51	47	41, 35, 27	34

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$
$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #8

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-10-17
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: C - 75% Fly Ash

MIX NO.	B1	AVG.	B2	AVG.	B3	AVG.	B4	AVG.
Compressive Strength, MPa								
@ 7 days	11.0, 10.4	10.7	9.9, 9.7	9.8	10.5, 10.3	10.4	10.9, 10.8	10.9
@ 28 days	21.0, 21.0	21.0	20.7, 20.5	20.6	22.0, 21.0	21.5	22.0, 20.7	21.4
@ 56 days								
Flexural Strength, MPa							*2.7	2.7
@ 28 days	2.8,2.8,2.9	2.8	2.6,2.7,2.7	2.7	3.1,3.1,2.9	3.0	2.6,2.9,2.8	2.8
Toughness Index @ 28 days								
I_5	-	-	2.6,2.6,2.6	2.6	3.5,3.8,3.3	3.5	3.4,3.7,3.9	3.7
I_{10}	-	-	3.8,4.3,3.7	3.9	6.7,7.2,6.3	6.7	6.8,7.6,7.7	7.4
I_{20}	-	-	6.0,7.3,5.9	6.4	12.6, 13.3 11.8	12.6	13.3, 14.6 14.2	14.0
Residual Strength, % $RS(I_5, I_{10})$	-	-	24, 34, 22	27	64, 68, 60	64	68, 78, 76	74
$RS(I_{10}, I_{20})$	-	-	22, 30, 22	25	59, 61, 55	58	65, 70, 65	67

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$

$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

2) *First crack flexural strength was less than the ultimate flexural strength.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #9

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-10-17
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: C - 75% Fly Ash

MIX NO.	C1	AVG.	C2	AVG.	C3	AVG.	C4	AVG.
Compressive Strength, MPa								
@ 7 days	5.4, 5.2	5.3	5.0, 5.2	5.1	3.7, 3.7	3.7	7.2, 7.0	7.1
@ 28 days	12.1, 12.1	12.1	12.1, 12.2	12.2	8.9, 8.7	8.8	14.3, 14.6	14.5
@ 56 days								
Flexural Strength, MPa							*1.9 *1.9	1.9
@ 28 days	2.0,2.0,1.7	1.9	1.8,1.8,1.8	1.8	1.5,1.4,1.3	1.4	2.1,1.9,2.0	2.0
Toughness Index @ 28 days								
I_5	-	-	2.5,2.9,2.4	2.6	4.0,3.4,3.7	3.7	5.1,3.8,4.9	4.6
I_{10}	-	-	3.8,4.6,3.6	4.0	7.9,6.5,6.8	7.1	9.8,7.6,9.9	9.1
I_{20}	-	-	6.7,8.0,5.9	6.9	14.8, 12.4 12.1	13.1	17.2, 14.0 15.6	15.6
Residual Strength, %								
RS(I_5, I_{10})	-	-	26, 34, 24	28	78, 62, 62	67	94, 76, 100	90
RS(I_{10}, I_{20})	-	-	29, 34, 23	29	69, 59, 53	60	74, 64, 57	65

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$

$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

2) *First crack flexural strength was less than the ultimate flexural strength.

TECHNICIAN: N. M^{c}Askill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #10

TO:
SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-10-20
CLIENT P.O.
C.C.

ATTENTION: Mr. W. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT
SUBJECT: PROPOSED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

Mix No.	U	V	W	X	Y	Z
Fibre Dosage, kg/m^3 FORTA CR-38 mm	0	3	6	0	3	6
Type 10 Cement, kg/m^3	150	150	150	160	160	160
Fly Ash, kg/m^3	250	250	250	290	290	290
10 x 5 mm Coarse Aggregate (SSD), kg/m^3	500	495	490	470	465	460
Sand (SSD), kg/m^3	1160	1150	1140	1100	1090	1080
Water 1/m^3 (estimate)	145	145	145	155	155	155
Superplasticizer 1/m^3 DURASAR (estimate)	4	5	7	4	6	8
W/C + FA Ratio	0.36	0.36	0.36	0.34	0.34	0.34
Slump before fibre addition, mm	80±20	80±20	80±20	80±20	80±20	80±20
Slump after fibre addition, mm	80±20	80±20	80±20	80±20	80±20	80±20
Air Content % (after shooting)	7±1%	7±1%	7±1%	7±1%	7±1%	7±1%

DESIGNED BY: ____________________
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

APPENDIX B

PHASE I INVESTIGATIONS - HARDY BBT LTD.

3 CONCRETE REINFORCEMENT
Crack-Control Reinforcement

FORTA Corporation
November 1987
(Supersedes November 1985)

FORTA™

SPEC-DATA®

This Spec-Data sheet conforms to editorial style prescribed by The Construction Specifications Institute. The manufacturer is responsible for technical accuracy.

1. PRODUCT NAME

FORTA™ CR® (Concrete Reinforcement)

2. MANUFACTURER

FORTA Corporation
100 Forta Drive
Grove City, PA 16127-9990
Phone: 1-800-245-0306
1-800-222-8907 in PA
1-412-458-5221
Telex: 812 535 FORTA GRCT
FAX: 412-458-8331

3. PRODUCT DESCRIPTION

General Description: FORTA CR is a twisted bundle, CFP (collated fibrillated polypropylene) fibrous reinforcement.

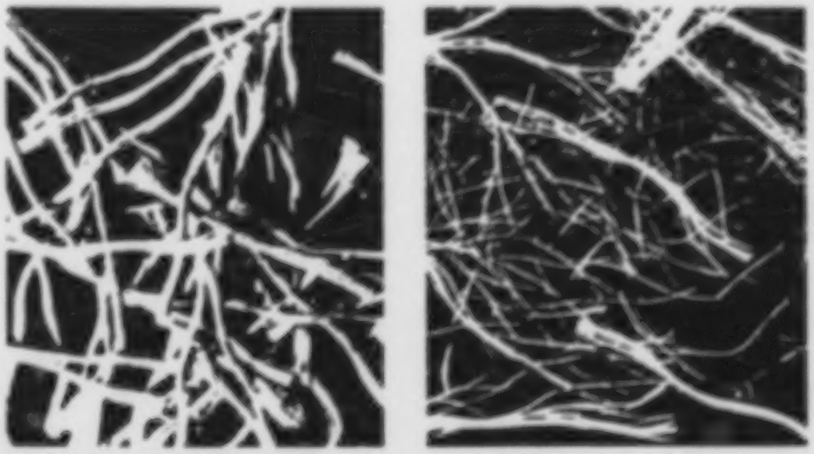
Basic Use: FORTA CR is used as a secondary, crack-controlling reinforcement for concrete. FORTA CR may be used to replace welded wire fabric (wire mesh) in any application where the mesh is used as temperature/shrinkage reinforcement.

General Applications: Major application areas for FORTA CR include cast-in-place concrete, air-placed concrete, and precast concrete elements.

Cast-in-place applications include industrial floors, parking lots, pavements, and residential concrete. Air-placed applications include water reservoir liners, irrigation ditches, tunnel and culvert liners, man-made rock and waterscapes, and bridge deck overlays. Precast concrete uses include wall panels, septic tanks, vaults, and various ornamental products.

Benefits: From an economic standpoint, the use of FORTA CR eliminates the costs associated with the handling and placement of wire mesh in both site-cast and precast applications. From a technical value-added standpoint, the uniform, three-dimensional fibrous distribution allows FORTA CR to control cracking better than the single-plane layer of wire mesh. The single purpose of wire mesh, when used as secondary/temperature reinforcement, is to hold the concrete together *after* it cracks. Due to the uniform fibrous reinforcement coverage, FORTA CR not only controls the cracking process more effectively, but also contributes to a number of additional concrete properties.

The additional benefits of FORTA CR include the reduction of plastic and hardened concrete shrinkage and permeability, and improved impact resistance, ductility, fatigue strength, and toughness. Also, test data per ASTM C-944 shows that FORTA CR significantly reduces floor surface abrasion as compared to plain concrete.



Twisted FORTA™ CR® bundles spring open during mixing.

Limitations: FORTA CR is considered as a secondary reinforcement. FORTA CR will not replace primary reinforcement intended to support structural loads. FORTA Corporation's engineering group will assist in evaluating any potential application.

Dosage Rates: FORTA CR is packaged in 1.6 pound bags, which is the recommended quantity for one cubic yard of concrete. For metric applications, FORTA CR is packaged in one kilogram bags. These dosage rates have been determined by engineering testing and by extensive use of FORTA CR in conventional applications where wire mesh is being replaced as a secondary reinforcement. Higher volumes per cubic yard have shown improvement to the toughness index of the fibrous concrete—consult FORTA Corporation for additional details.

Four twisted fibrous bundle lengths are manufactured by FORTA Corporation. The fibrous bundle length is matched with the maximum top-size of the coarse aggregate used in the mix. The effective bond length of a fibrous reinforcement is approximately 50% of the actual bundle length. Therefore, resistance to pull out/debonding and the utilization of the material's ultimate tensile strength are realized when the longest bundle length that can be properly mixed and uniformly distributed in a given mix is specified. (See bundle length per aggregate size chart in Table 1.)

Table 1

PRODUCT TYPE	BUNDLE LENGTH	AGGREGATE TOP-SIZE	AASHTO SIZE
A-5	¾"	⅜"−	10−
A-10	1½"	½"	8−
D-15	2¼"	¾"	67−
D-24	2½"	1"+	57+

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Approvals—Specifications: For precast septic tank and water distribution box products, FORTA Corporation has obtained approvals from numerous state and local agencies for use as secondary/handling reinforcement in lieu of wire mesh. (Contact FORTA Corporation for specific approvals.) For flatwork, both I.C.B.O. Evaluation Report #4151 (in compliance with the 1985 Uniform Building Code) and FORTA's U.S.–GSA Contract #G.S.-00F-79582 (for federal government purchase) are available to the architect and engineer upon request.

FORTA Corporation suggests that current consensus standards and practices be followed in the design, placing, and finishing of concrete.

4. TECHNICAL DATA

Chemical: FORTA CR consists of a virgin homo-polymer polypropylene in combination with other chemicals and additives defined by FORTA Corporation to meet precise engineering standards. FORTA CR is chemically inert and non-hazardous in the form supplied. FORTA CR will not react with any components found within the concrete, such as chemical admixtures, alkalis, or calcium chloride, and will not rot or corrode. Also, FORTA CR will not react with the components used to cure and seal the concrete, nor with the vast majority of materials that may come in contact with the concrete including organic acids. FORTA CR also contains a color additive to facilitate camouflaging with cured concrete and to enhance the surface U.V. stability. Both the FORTA Technical Report: Chemical Resistance of FORTA CR Fibrous Reinforcement and the O.S.H.A. Material Safety Data Sheet #20 (in voluntary, non-required compliance with O.S.H.A. Hazard Communication Standard, 29 CFR 1910.1200) are available upon request.

Physical Properties: Due to the chemically inert nature of FORTA CR and subsequent need for mechanical fibrous bonding with the cement matrix, FORTA Corporation utilizes a manufacturing process that is engineered solely to enhance the bonding of the FORTA in the concrete matrix. FORTA CR's fibrillation pattern (screen formation) is comprised of coarse main fibrils and lesser diameter connecting fibrils. This method reduces the risk of fibrous debonding and pull-out from the concrete matrix that would occur with small diameter unidimensional screen or monofilament fiber products.

Additional physical characteristic data include:

Specific Gravity	0.91
Density	56 lbs./cu. ft.
Modulus of Elasticity	0.70 x 10^6 p.s.i.
Tensile Strength	70,000 p.s.i. (Minimum)
Lengths	¾", 1½", 2¼", 2½"
Volume at 1.6 lb./cu. yd.	0.1%
Elongation at Break	8%
Per ASTM E84-80	
Flame Spread Index	1.6
Fuel Contribution	0.0
Smoke Density	0.0

5. INSTALLATION

Addition/Mixing Procedures: FORTA CR is very easy to add—one pre-weighed bag per cubic yard of concrete. It may be added with the coarse and fine aggregates at the batch plant, or directly to the mixer on the job site. When added at the batch plant with the other ingredients, no additional site mixing time is required. If added to the already mixed concrete, approximately three to five minutes of mixing are required. If a superplasticizer is used with the FORTA CR at 1.6 lb. per cubic yard, add and mix the FORTA CR first. We suggest that when adding FORTA CR to a ready mix truck, the concrete should be brought to the back of the mixer, especially if the drum contains less than 50% of capacity (i.e. for 4 cubic yards in a 10 yard capacity drum, back the concrete up to top of discharge and empty FORTA CR on top of concrete before mixing). Due to the twisted bundle configuration, it is not necessary to sprinkle or "ribbon" the FORTA CR into the mixing system.

The FORTA CR reinforced concrete can be mixed and pumped or air-placed with no special equipment necessary.

If a conventional slump test is required, perform the test in accordance with ASTM C143 prior to adding the FORTA CR. Using this conventional slump test will indicate a lower test value for fibrous concrete than for plain concrete with the same w/c ratio. If preferred, ASTM C995 can be used to measure the consistency and actual flowability of the fibrous reinforced concrete.

NOTE: Fibrous reinforced specimens should be externally vibrated and not internally rodded per ACI Committee 544 recommendations.

6. AVAILABILITY AND COST

Availability: FORTA CR can be purchased domestically and internationally. In the United States, orders are shipped from the factory within 24 hours by UPS, commercial carrier, or air freight.

Cost: The in-place cost (4" thick slab) is approximately $0.10 per square foot. Exact delivered costs may be obtained from a local FORTA dealer or from FORTA Corporation.

7. WARRANTY

FORTA CR is warranted to be free of defects and to meet all quality control standards set by the manufacturer. FORTA Corporation has no control over the design, production, placement, or testing of the concrete products in which FORTA CR is incorporated, therefore FORTA Corporation assumes no responsibility for the end products.

8. MAINTENANCE

Not applicable.

9. TECHNICAL SERVICES

Complete technical services and assistance are available by contacting the FORTA Corporation engineering group, or the local FORTA technical representative.

10. FILING SYSTEMS

SPEC-DATA® II

Sweet's Engineering Catalogue #03200/FOR

I.C.B.O. Evaluation, Report #4151

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HANDY

745, Ste-Rose St., La Prairie, Qué. J5R 1Z2

DURASAR
SUPER PLASTICIZER FOR CONCRETE

- DURASAR is a cost effective non-alkaline, extremely low sulfate and chloride free Superplasticizer. It is an efficient fluidifier and a high range water reducer agent (Superplasticizer) thereby contributing excellent rheological properties to concrete.
- DURASAR improves the flow properties of the mixture by breaking up cement agglomerates to produce lower viscosities.
- DURASAR Superplasticizer concrete does not show a high rate of slump loss.
- DURASAR will increase the mechanical properties of concrete; i.e. compressive and flexural strengths and modulus of elasticity.
- DURASAR's dispersion effect on cement particles improves the efficiency of hydration.

DURASAR can be used to produce:

- Flowing self-levelling concrete
- High early strength concrete
- Low water-to-cement ratio
- Very high strength concrete (100 MPa - 15,000 psi)
- Reduced water requirements by 20%-30%

- DURASAR can be used for:

  Pumping concrete
  Underwater applications
  Gunite applications
  Special shaped concrete slabs
  Precasting
  Architectural concrete

- DURASAR should be used for production of:

  Commercial concrete
  Fly ash concrete
  Blast furnace slag cement concrete
  Lightweight concrete
  Numerous cementitious systems

DURASAR meets the requirements of the Canadian Standards Specifications CAN3-A266.6-M85 Superplasticizing Admixtures for Concrete.

DATA
DONNÉES

DOSAGE:

DURASAR is normally used at a rate of 0.5-2.0 litres per 100 kg. (9.0-20.0 fluid oz. per 100 lb.) of cement. Other dosages may be required depending on specific conditions.

TYPICAL PROPERTIES:

Chemical classification:	Naphthalene sulfonate calcium salt
Appearance:	Clear, brown liquid
Active content:	38.0% ± 1.0%
Sulfate percentage:	0.20% ± 0.05%
pH 10% solution	7.5 ± 0.5
Specific gravity at 23° C.	1.19 ± 0.02
Freezing point	-4.0° C. (25° F)
Chlorides	Nil
Ionic nature	Anionic
Solubility, aqueous	Clear, instantly in hard, or soft water

WORKABILITY:

DURASAR fluidified concrete remains workable for approximately one hour at 20° C. (68° F). The duration of workability depends not only on temperature, but also on the type and brand of cement, the nature of the aggregates and the method of transportation. When DURASAR is used at normal suitable dosage levels, it will not significantly affect the concrete's heat of hydration.

PACKAGING, STORAGE AND HANDLING:

DURASAR is supplied in 260 Kg. drums or in bulk. It will freeze at -4.0° C. (25° F.). If frozen, warm to 22° C. (72° F.) mix well. Its working properties will not be affected if frozen. Storage of DURASAR at room temperature is recommended.

SAFETY AND HANDLING PRECAUTIONS:

DURASAR is a non-alkaline material. Direct contact may cause irritation of eyes. Prolonged contact may cause skin irritation. May be harmful if swallowed. Do not get in eyes. Avoid prolonged skin contact. Wash thoroughly after handling. Do not take internally.

WARRANTY STATEMENT:

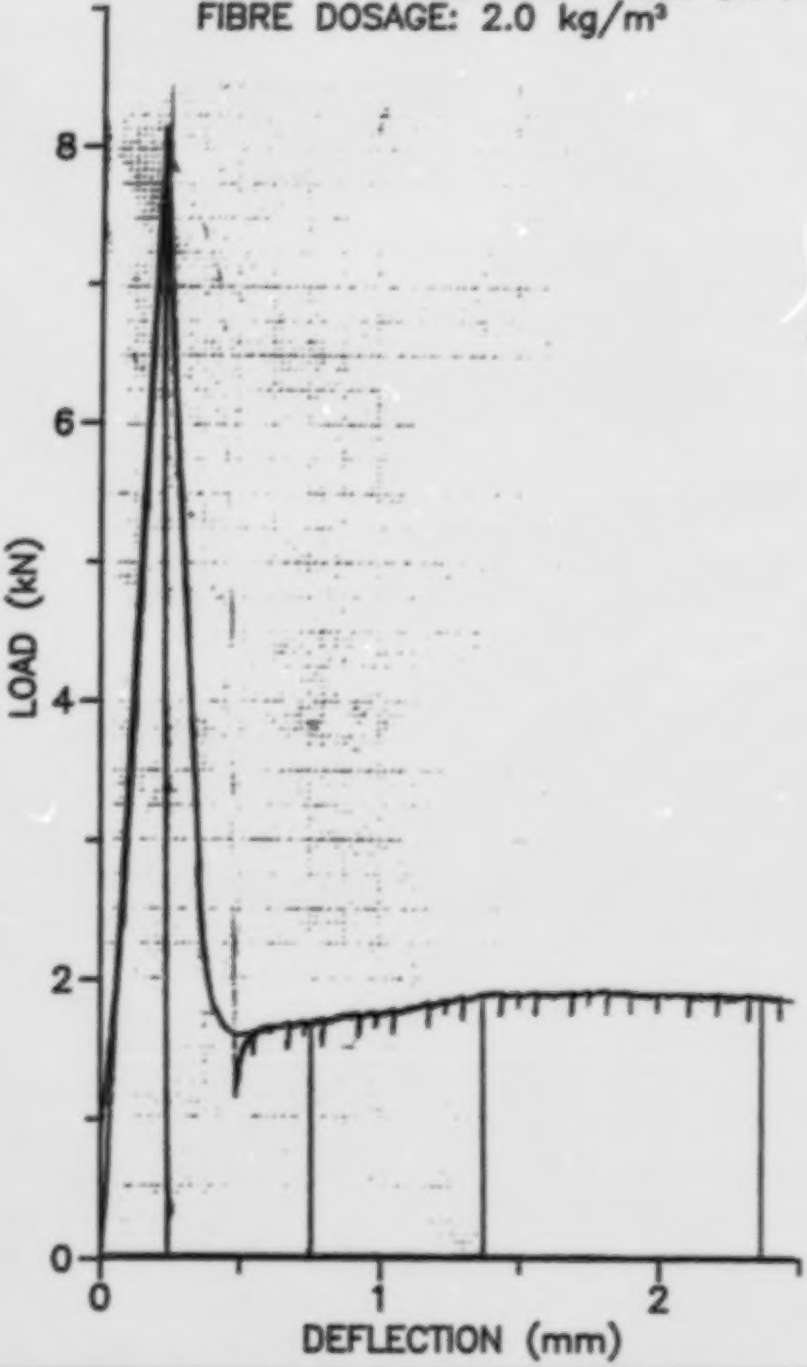
The information given here is based on our best knowledge and we believe it to be true and accurate. We assume no responsibility for the use of these statements, recommendations or suggestions, nor do we intend them as a recommendation for any use which would infringe any patent or copyright.

MANUFACTURED BY:- HANDY CHEMICALS LIMITED
745 Ste. Rose Street
La Prairie, Quebec
CANADA J5R 1Z2

Telex: 05-24489 Tel.: (514) 659-9693

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A2-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

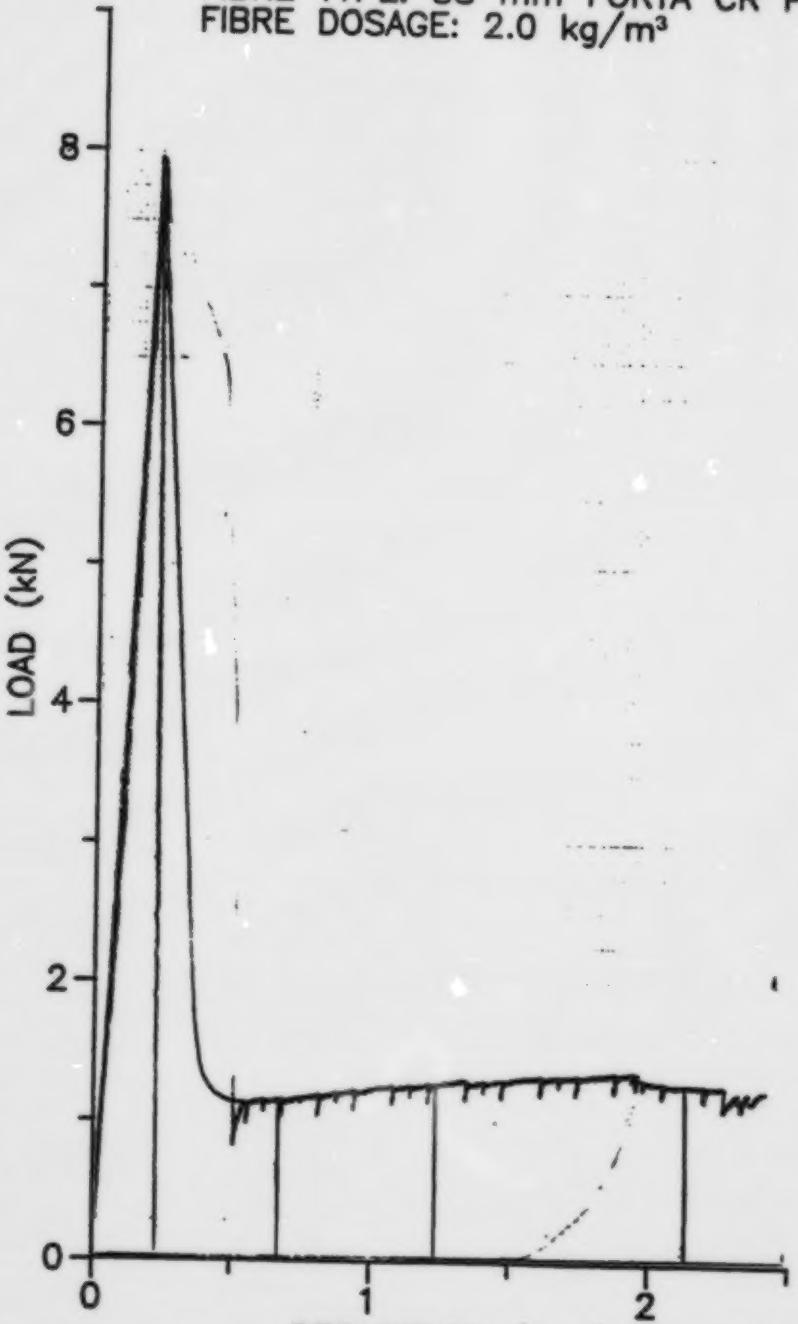
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-8785

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A2-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



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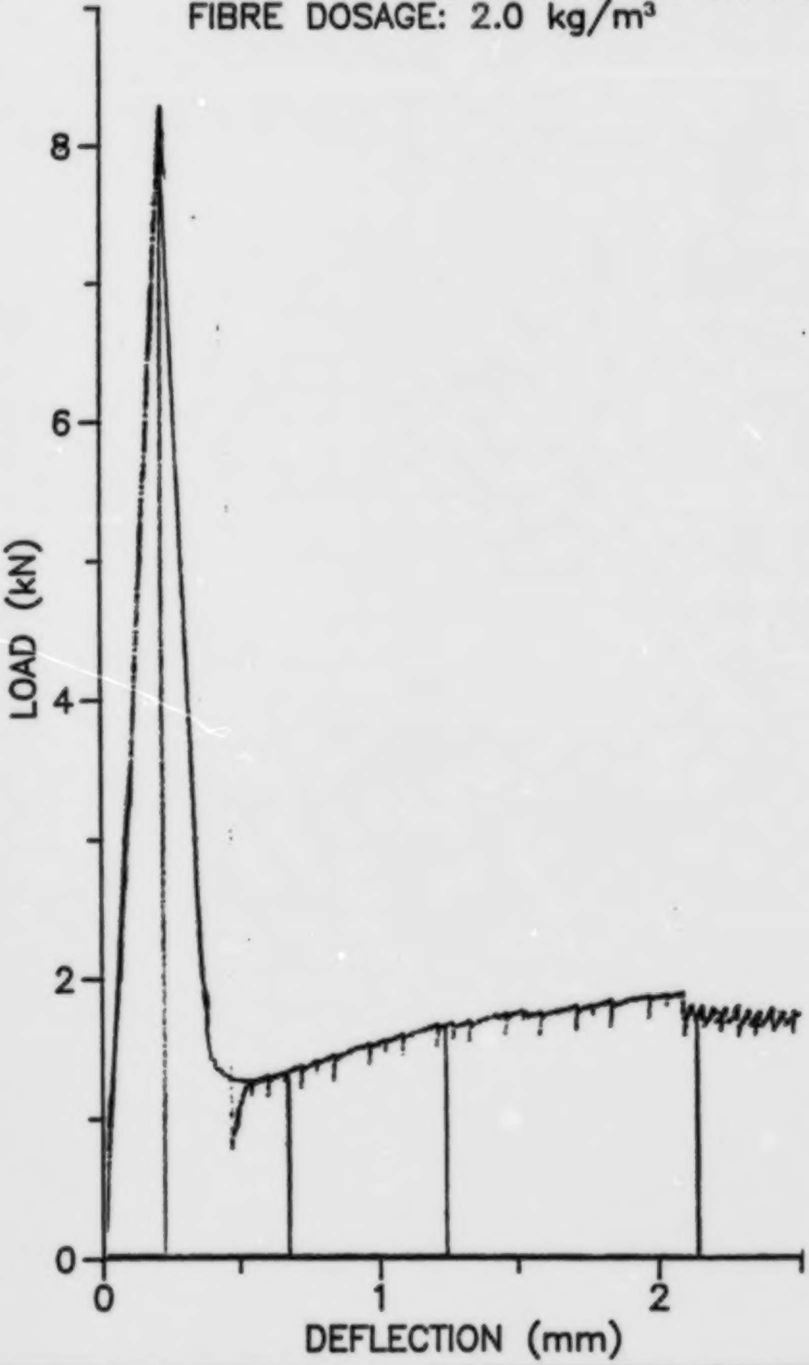
HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A2-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



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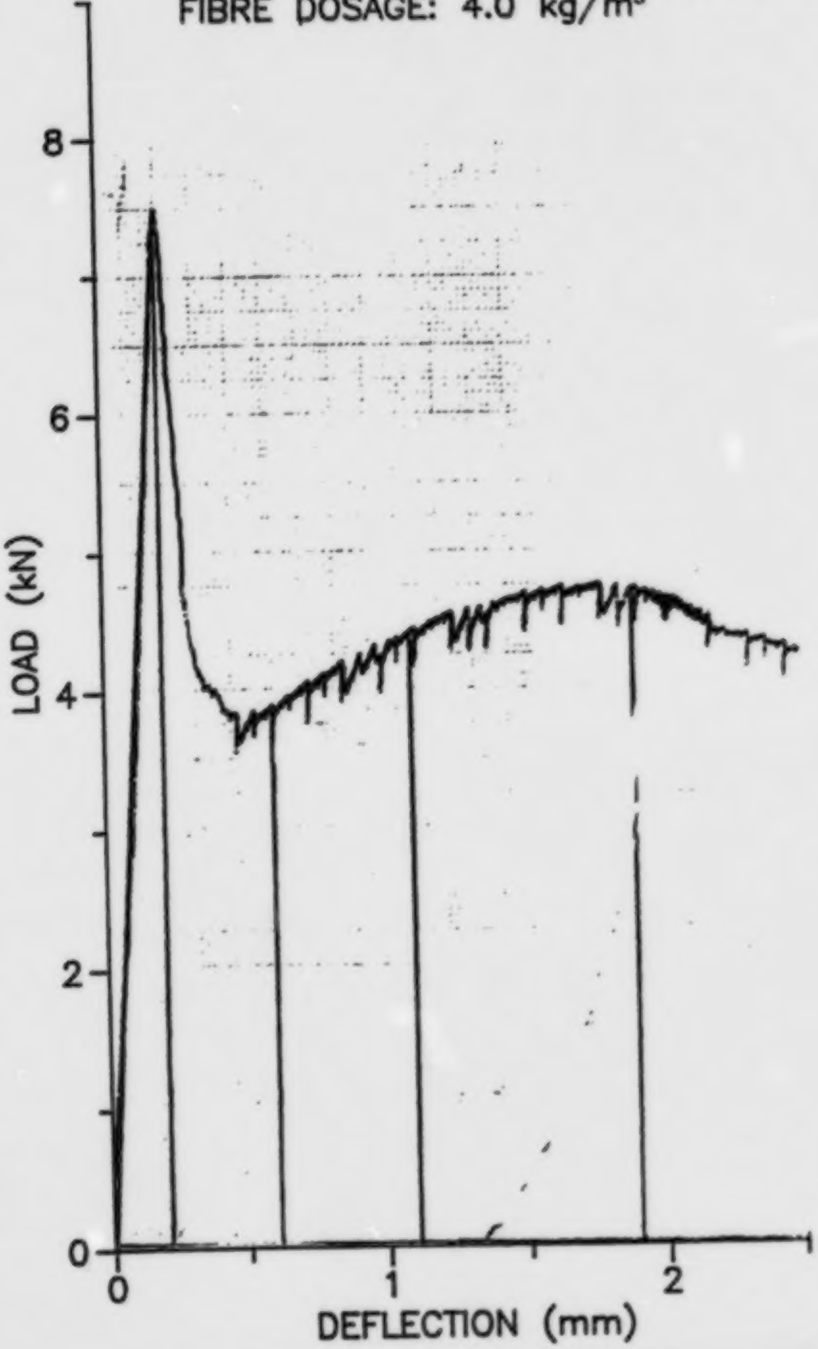
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018–85

SPECIMEN NO.: A3–1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



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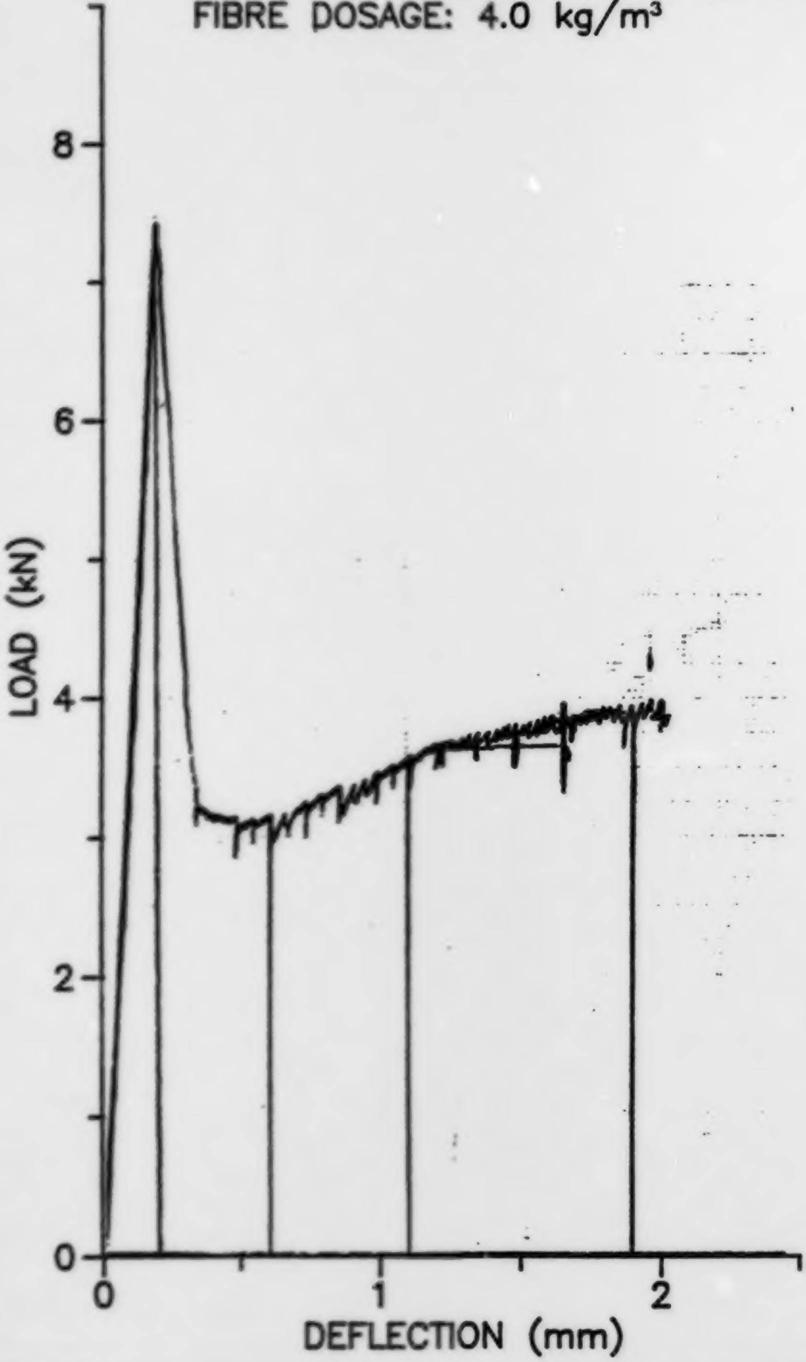
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A3-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



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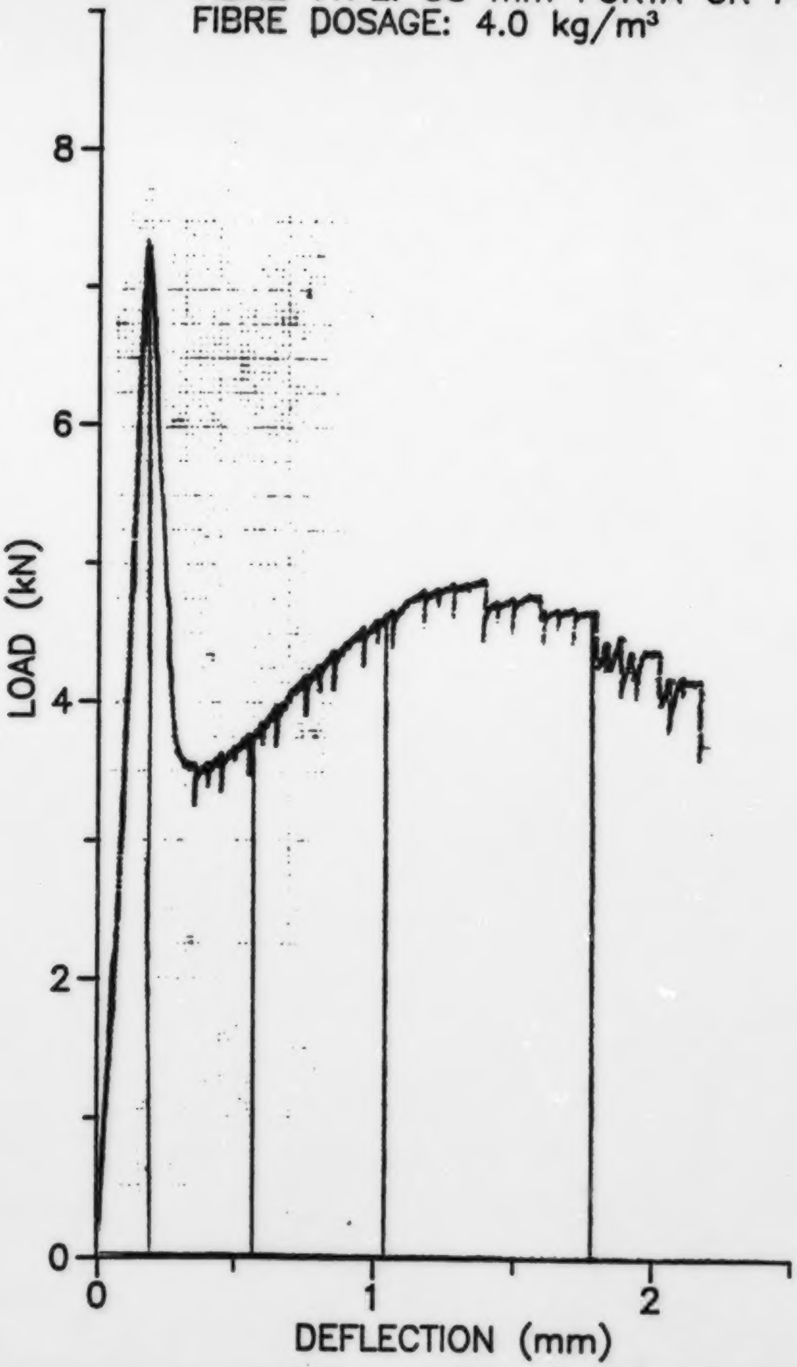
SPECIMEN NO.: A3-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m^3



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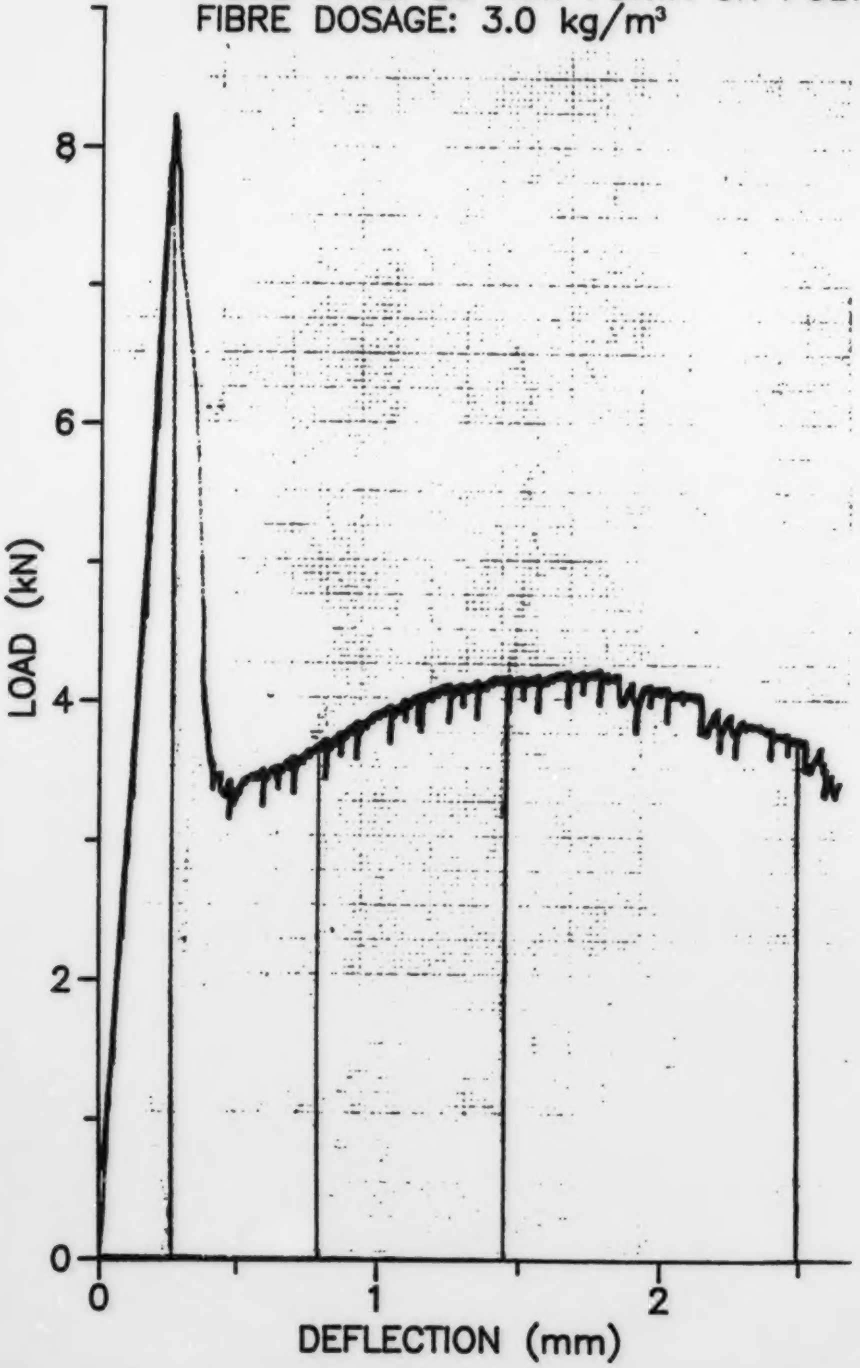
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A4-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.0 kg/m³



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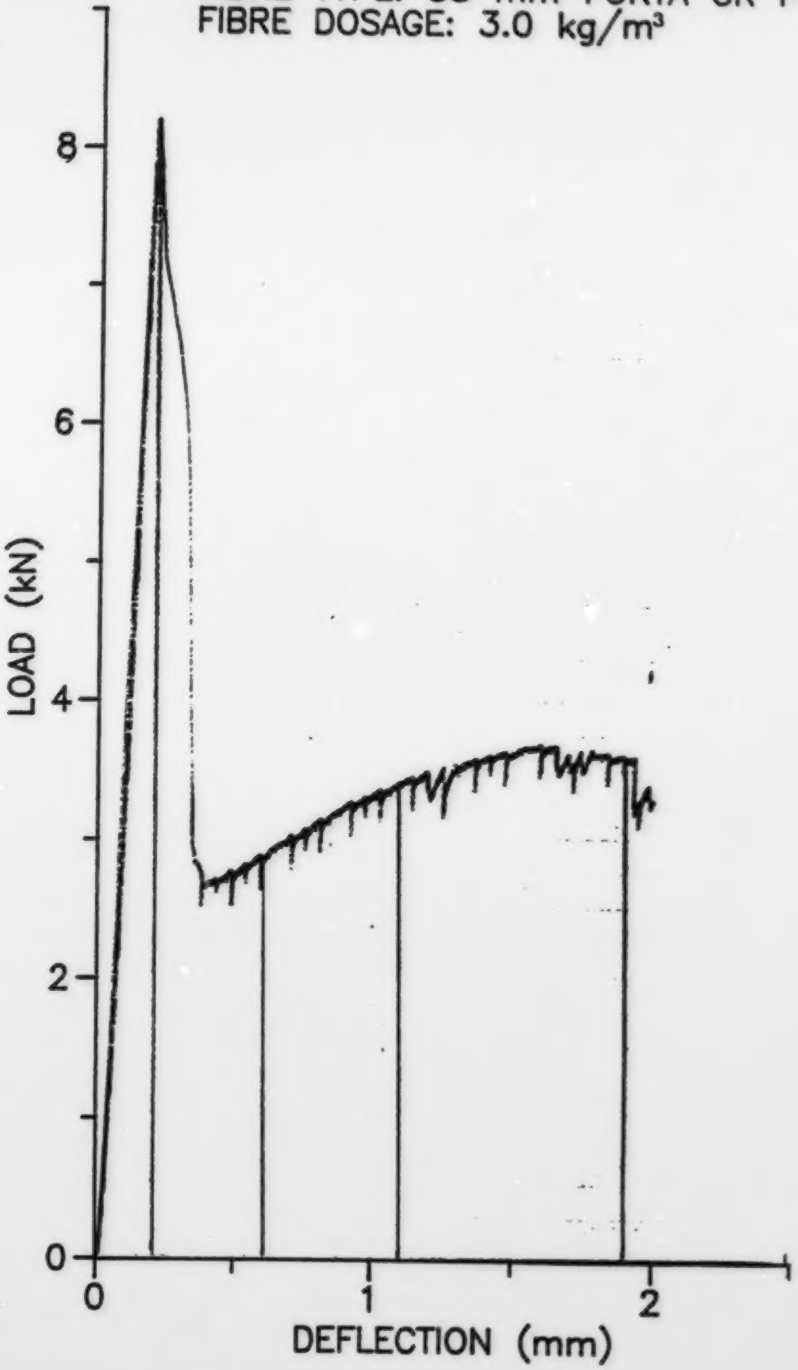
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

X

SPECIMEN NO.: A4-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.0 kg/m³



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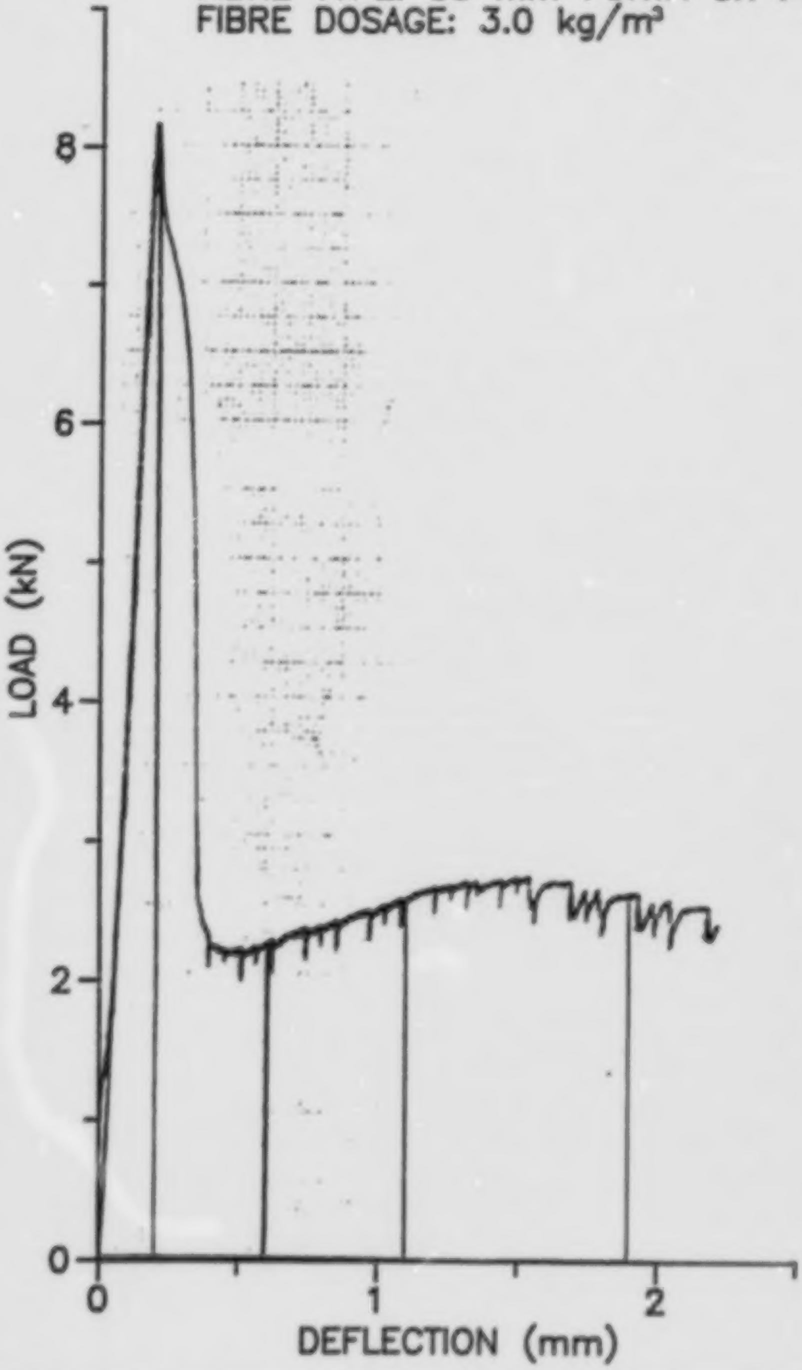
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: A4-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.0 kg/m³



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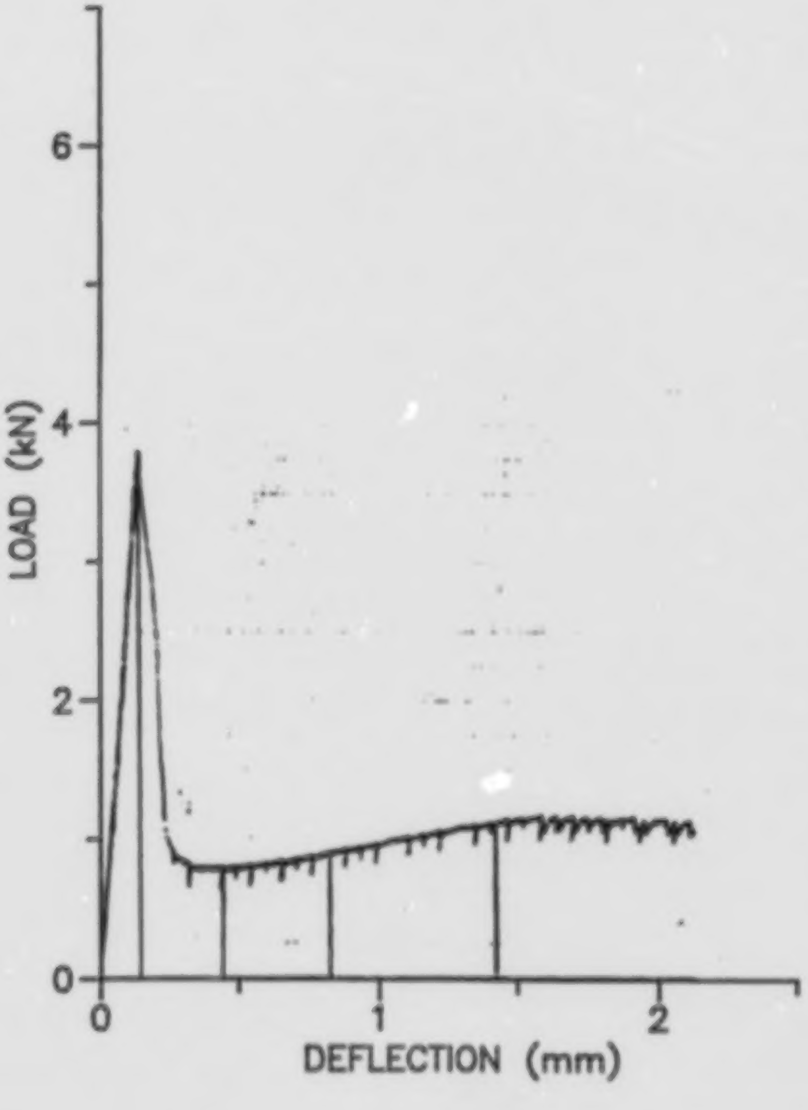
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B2-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



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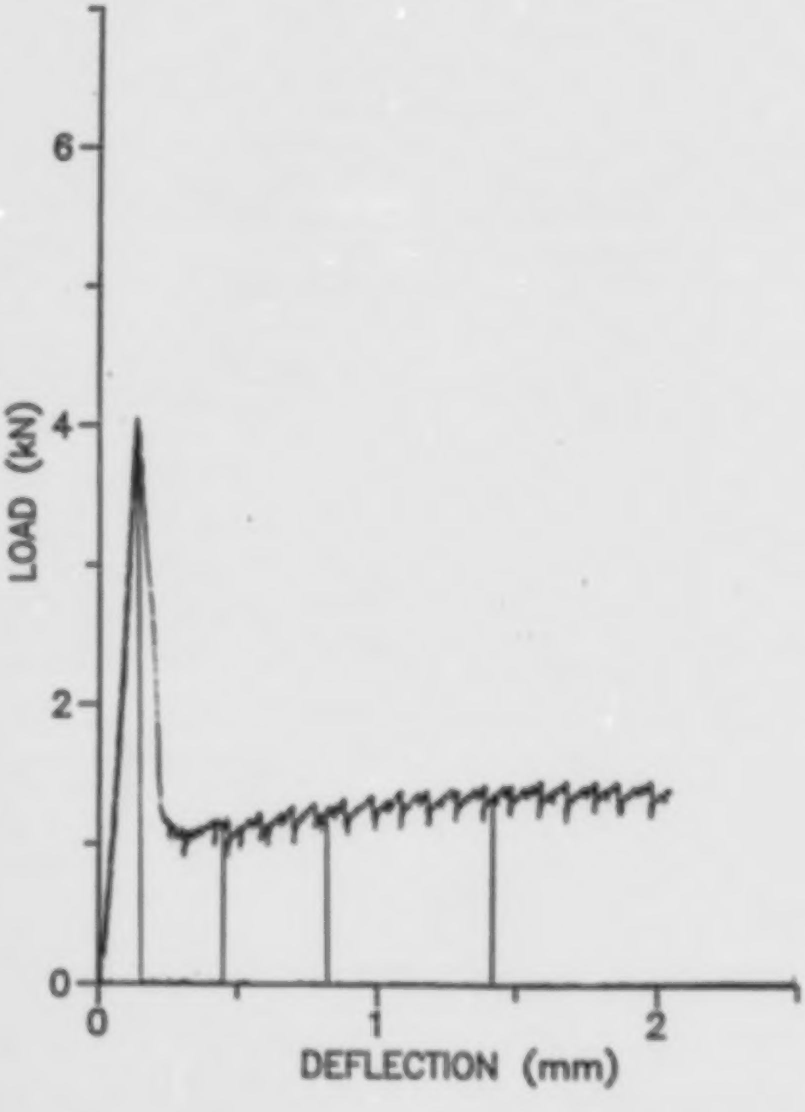
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B2-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



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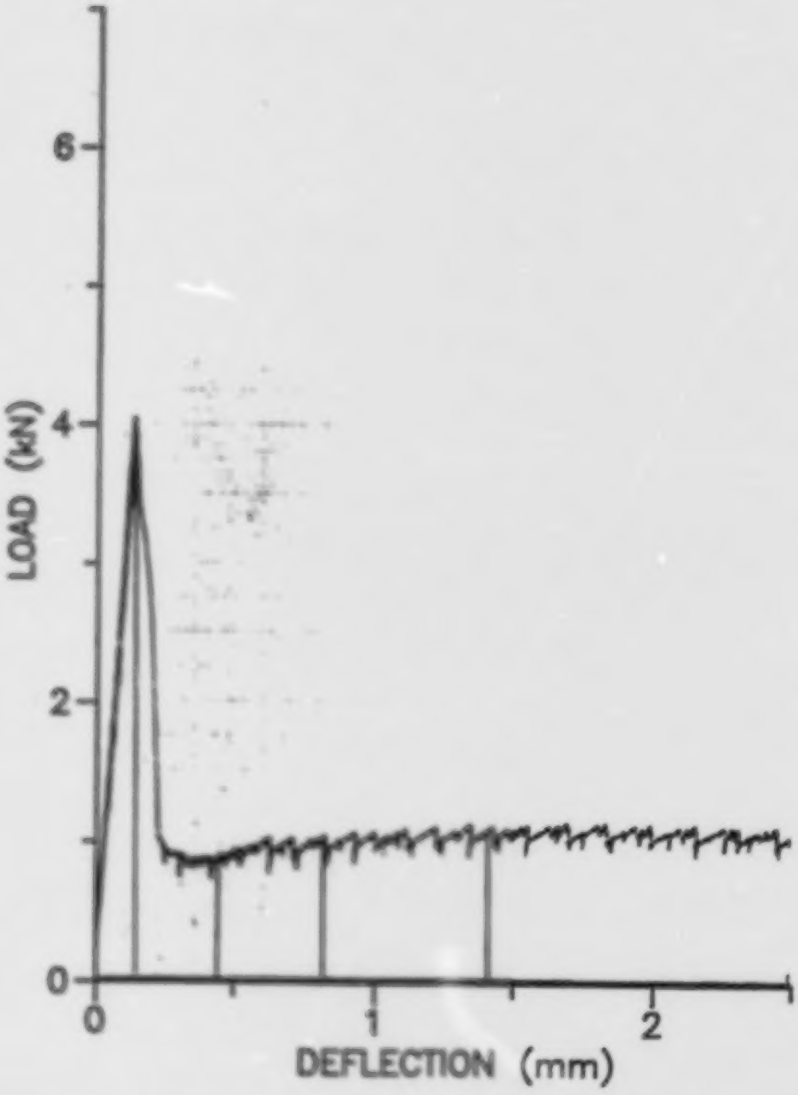
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B2-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



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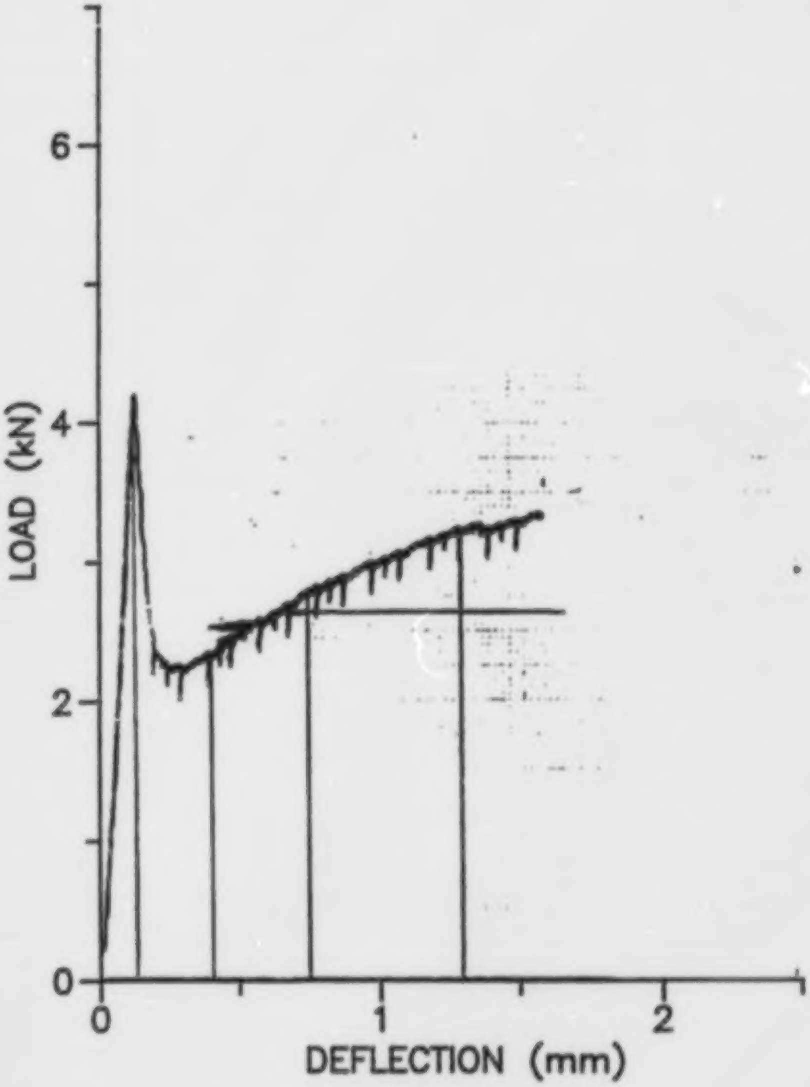
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B3-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



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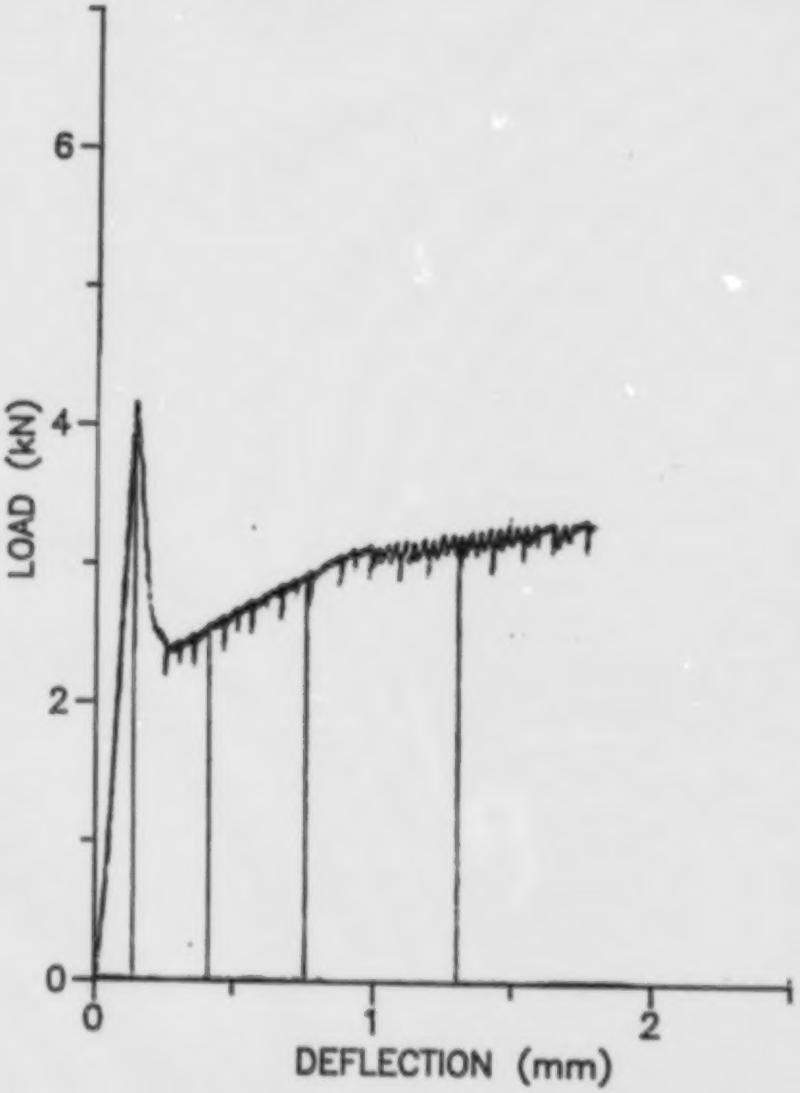
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B3-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



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Scale	Date	Drawn By
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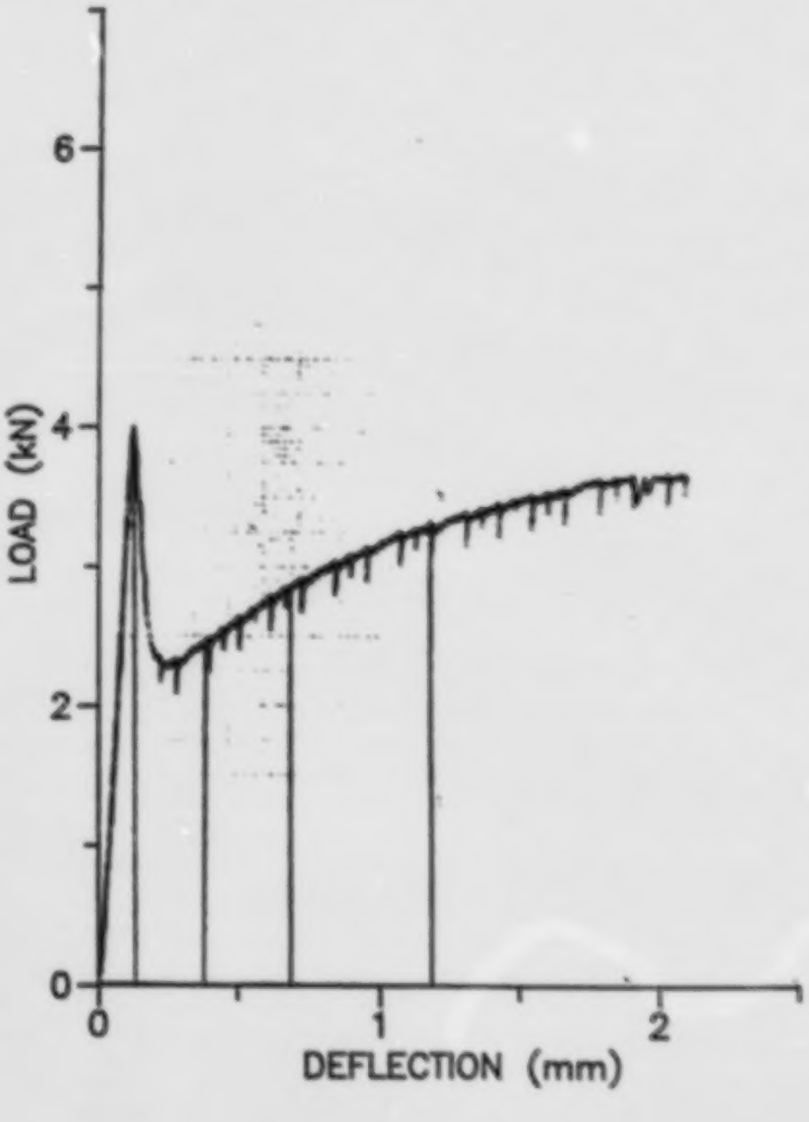
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B3-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



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PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
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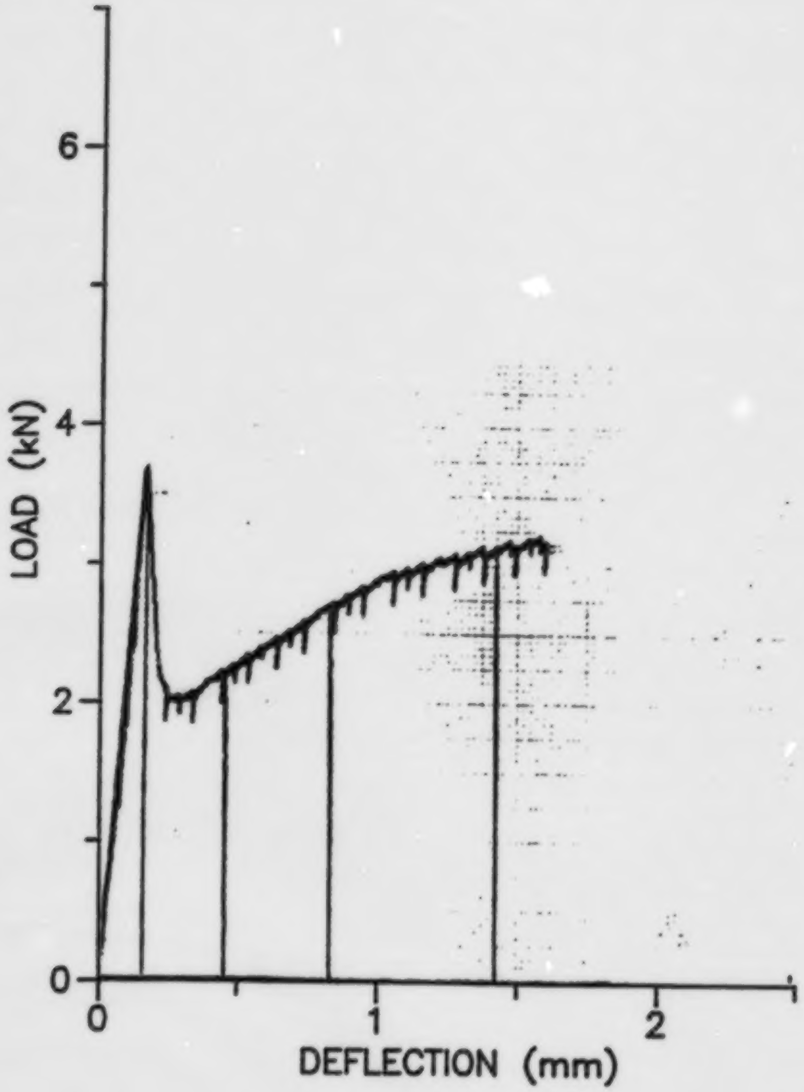
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B4-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³



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PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

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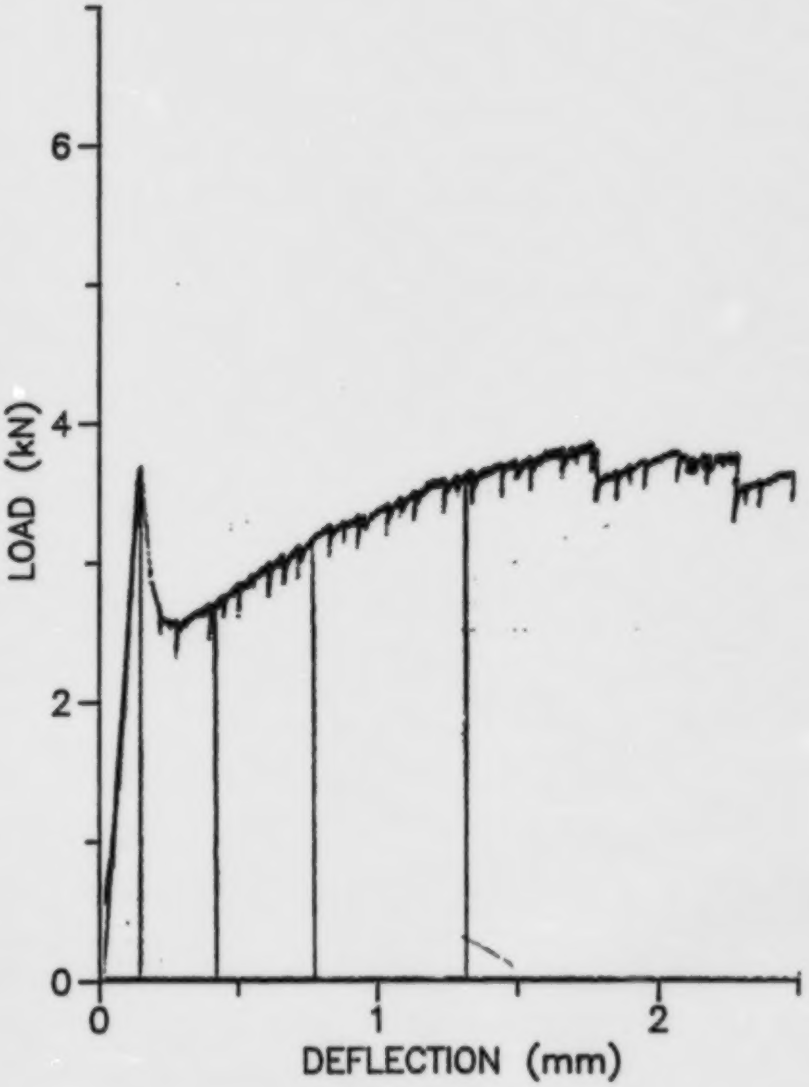
FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B4-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³

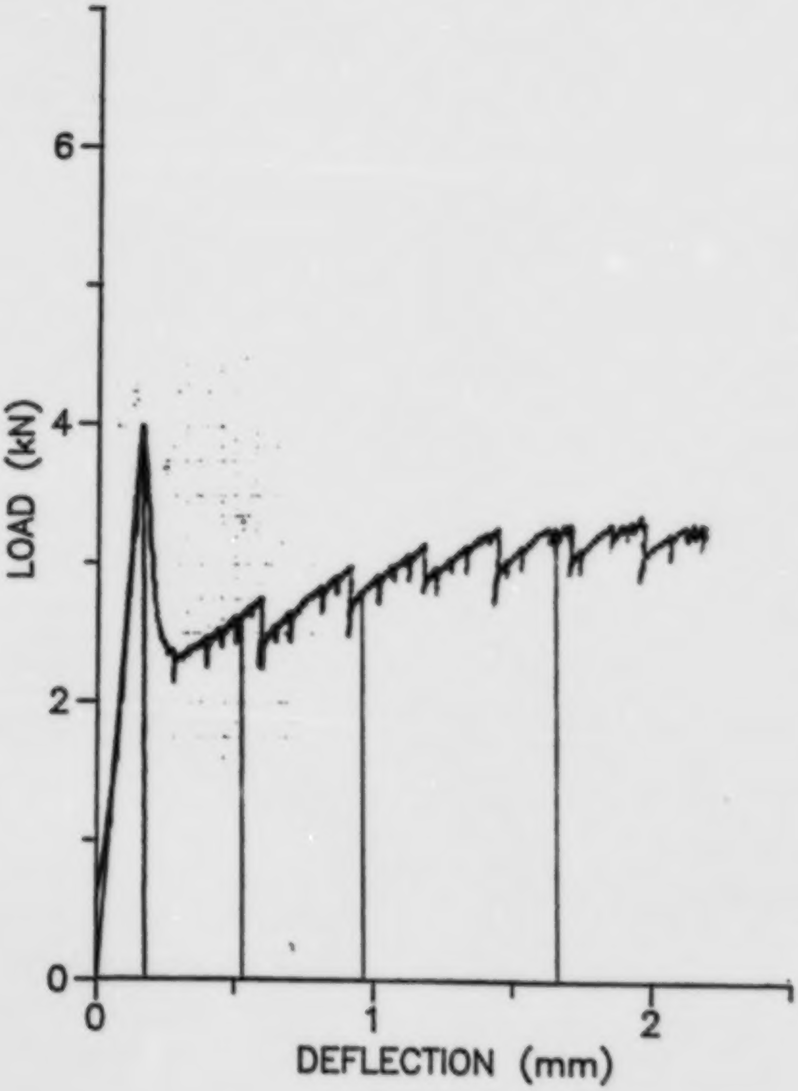


Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES	PROJECT: HIGH VOLUME FLY ASH PFRS CLIENT: SUPPLY AND SERVICES CANADA JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: B4-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

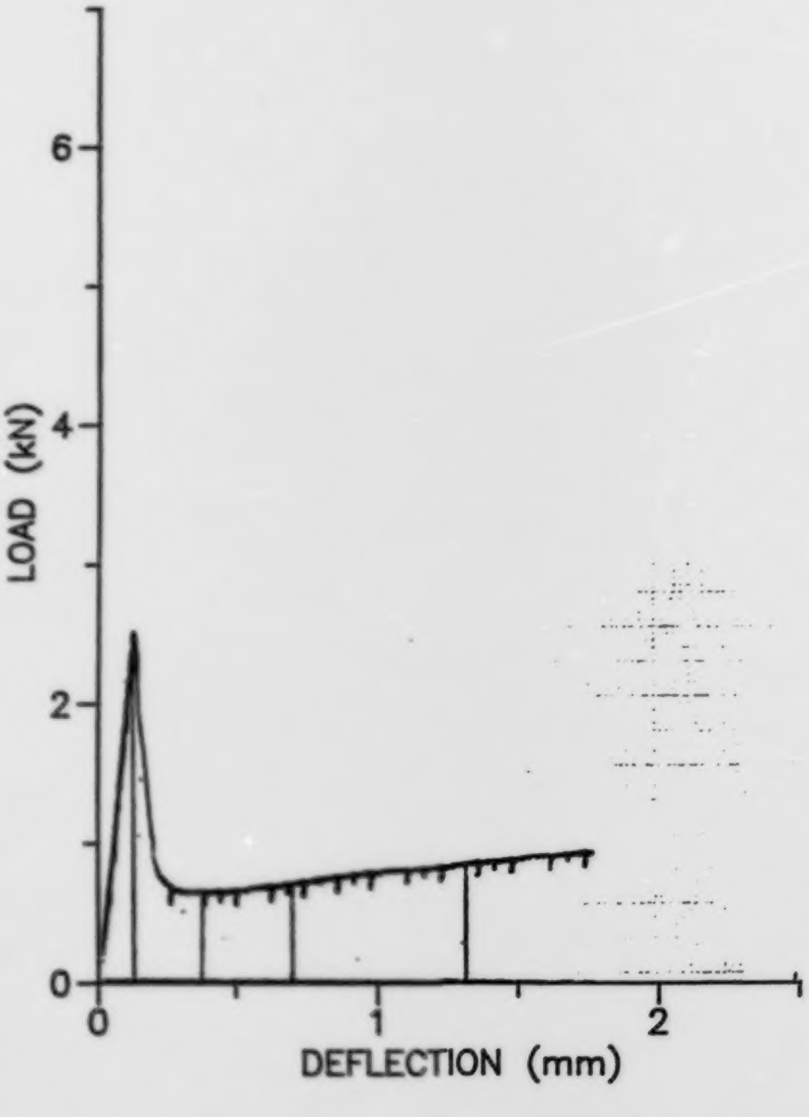
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C2-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

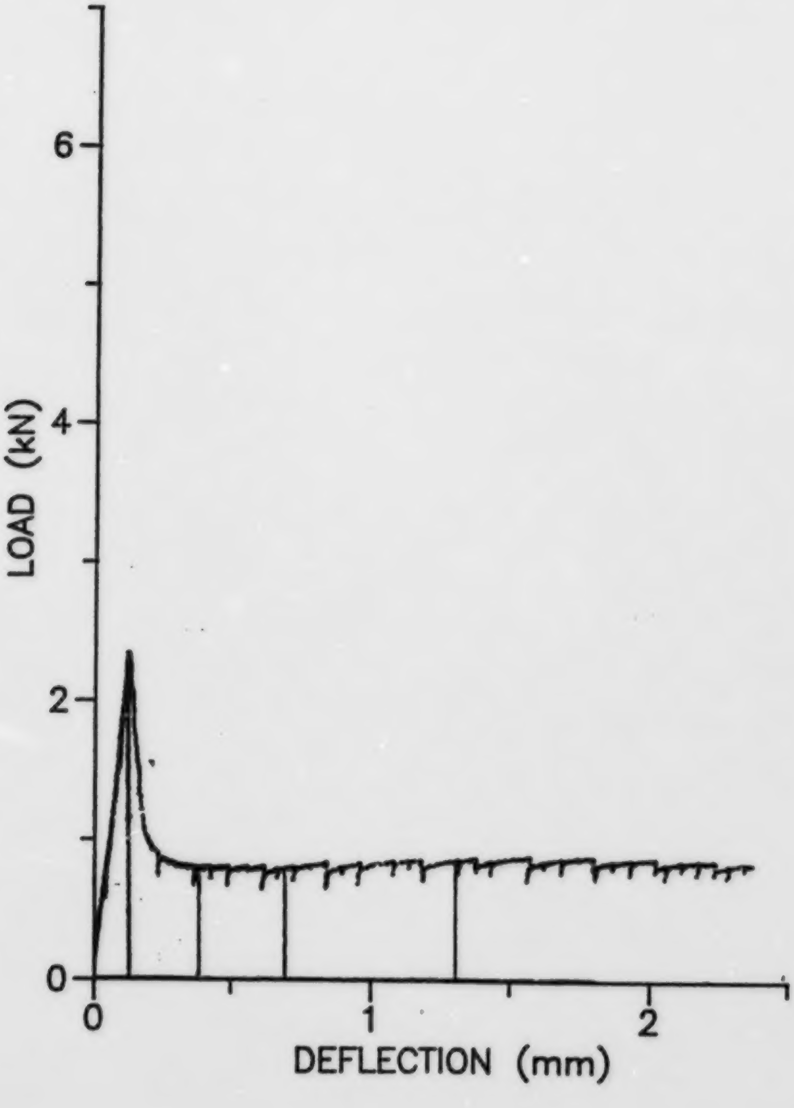
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-[illegible]

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C2-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

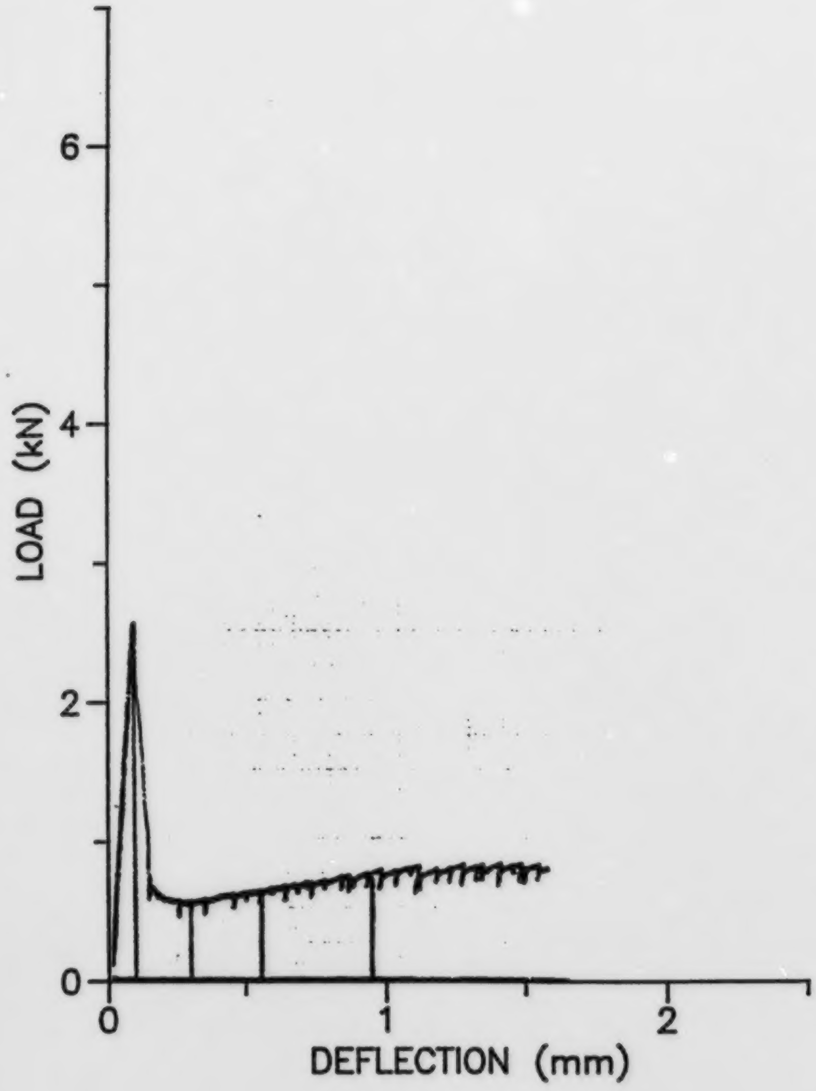
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C2-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 2.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

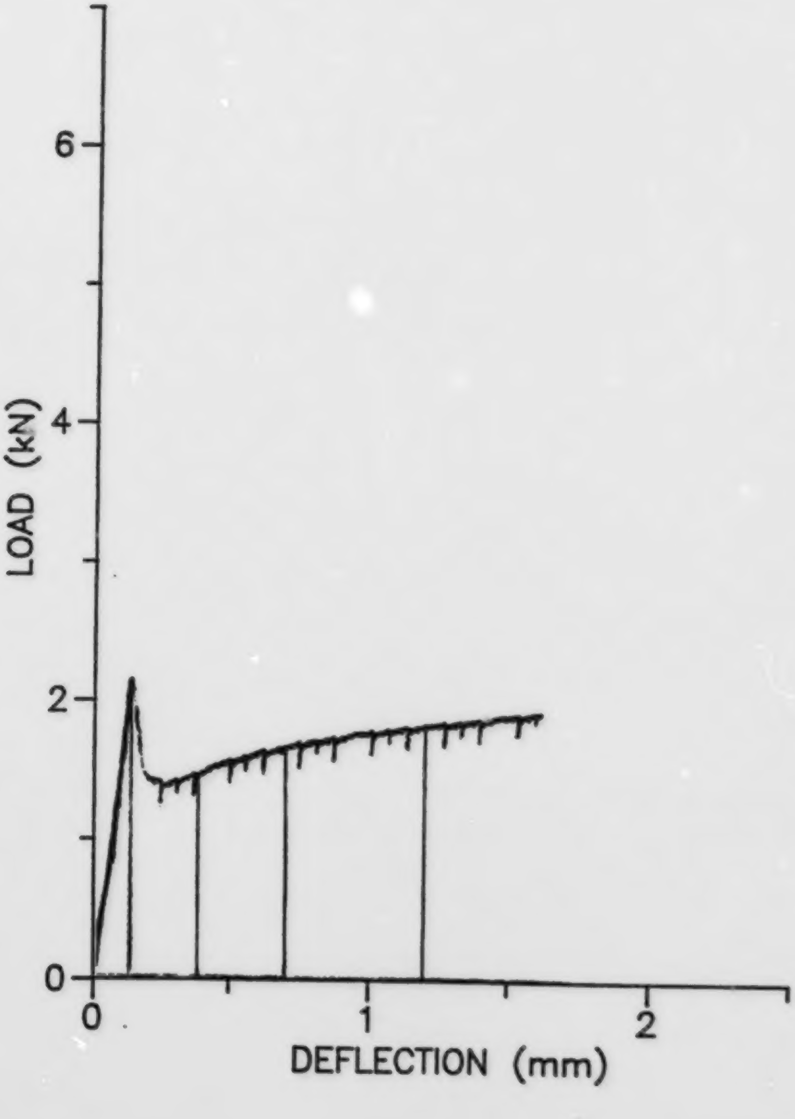
Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C3-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³

X



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

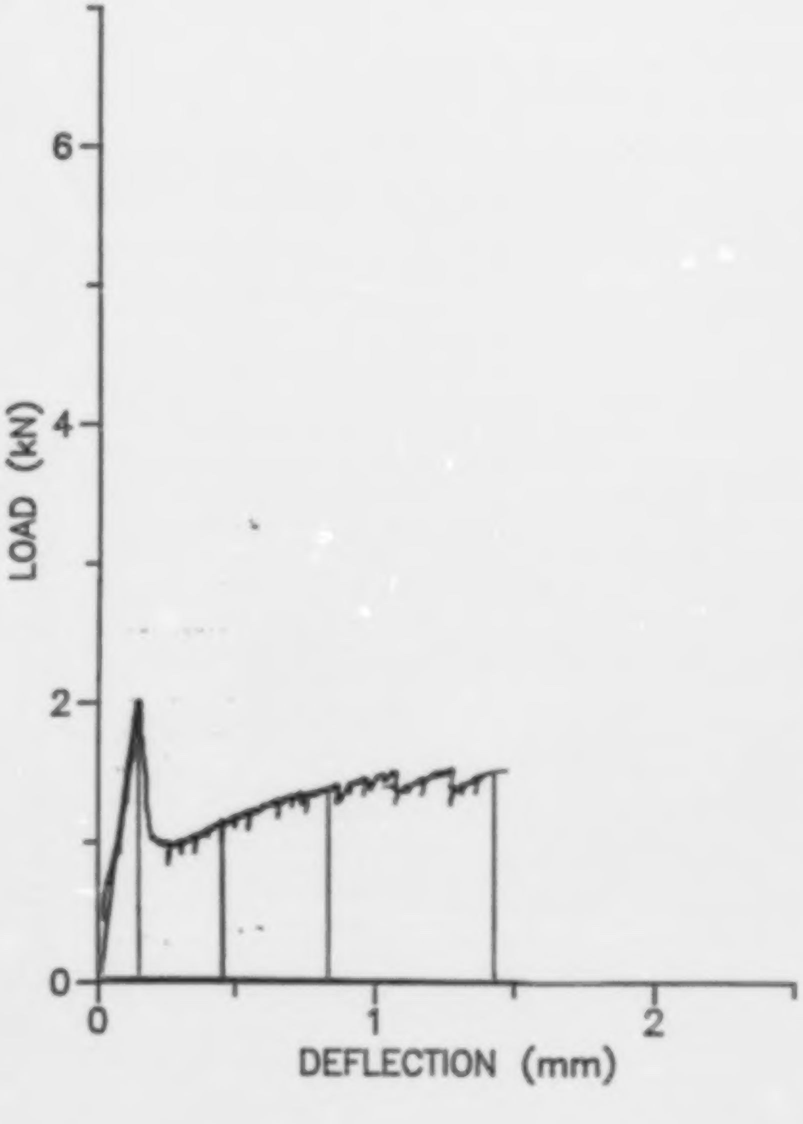
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C3-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

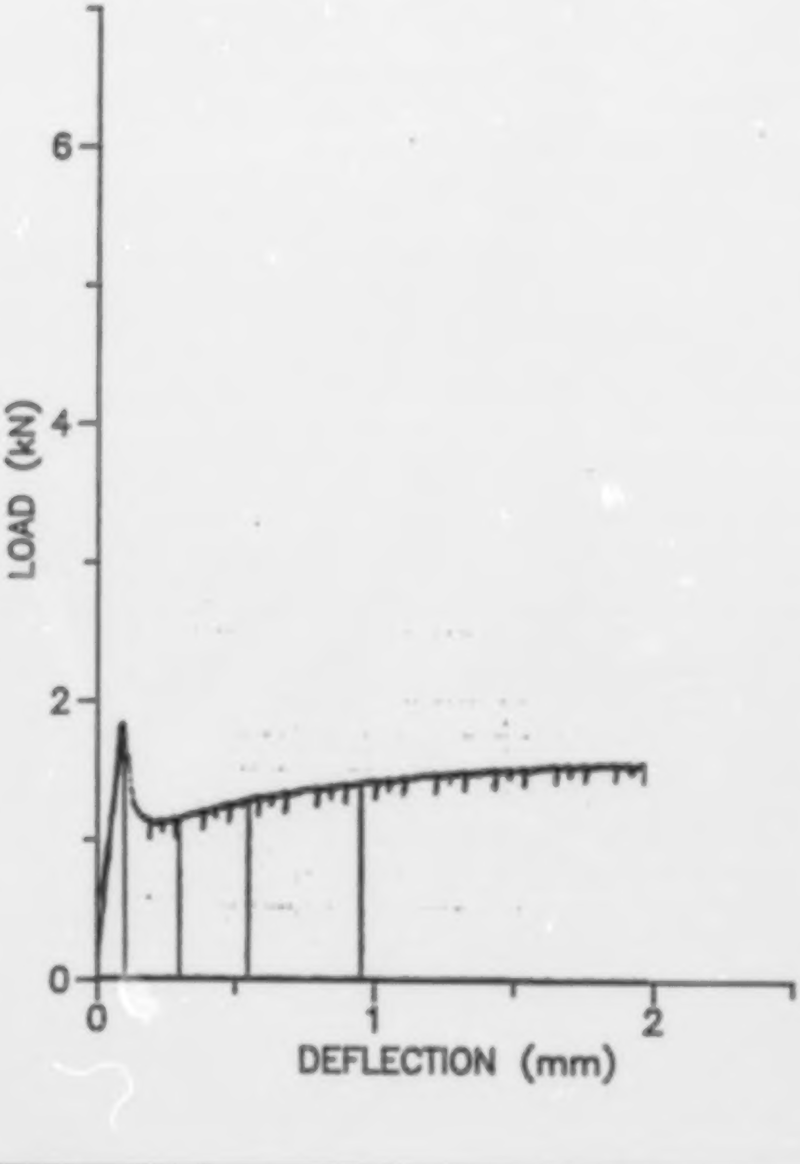
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C3-3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 4.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

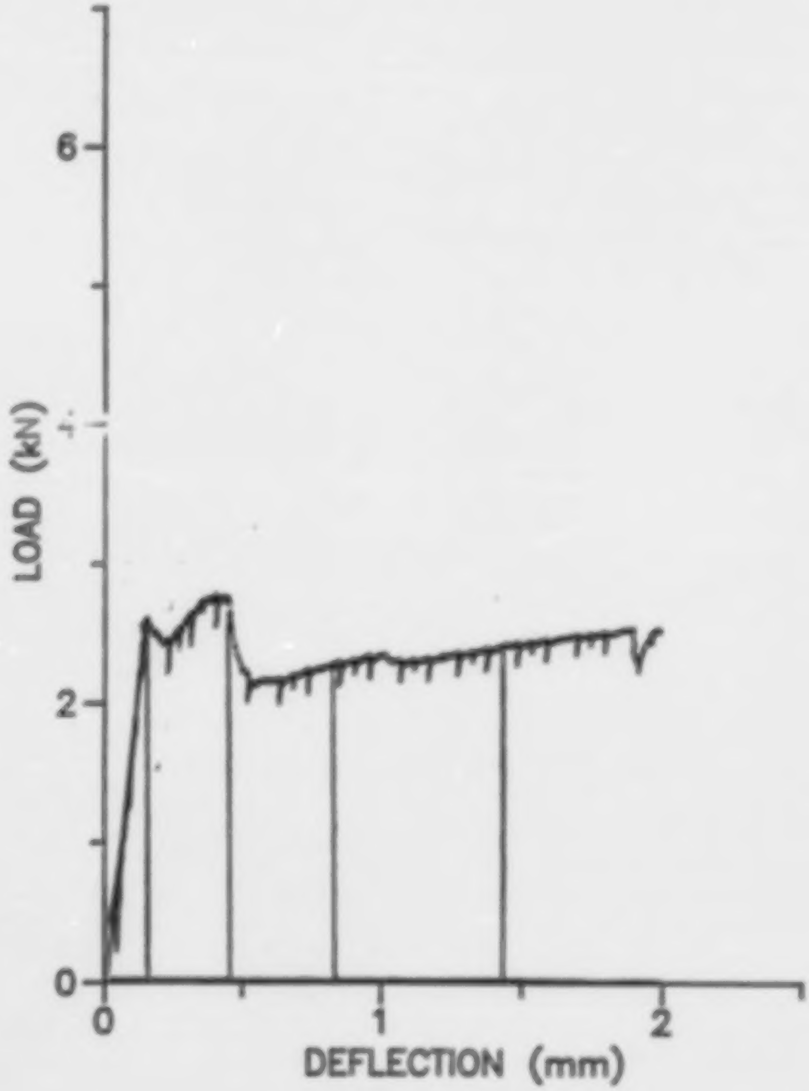
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

HBLT 11-87/05

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C4-1 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³



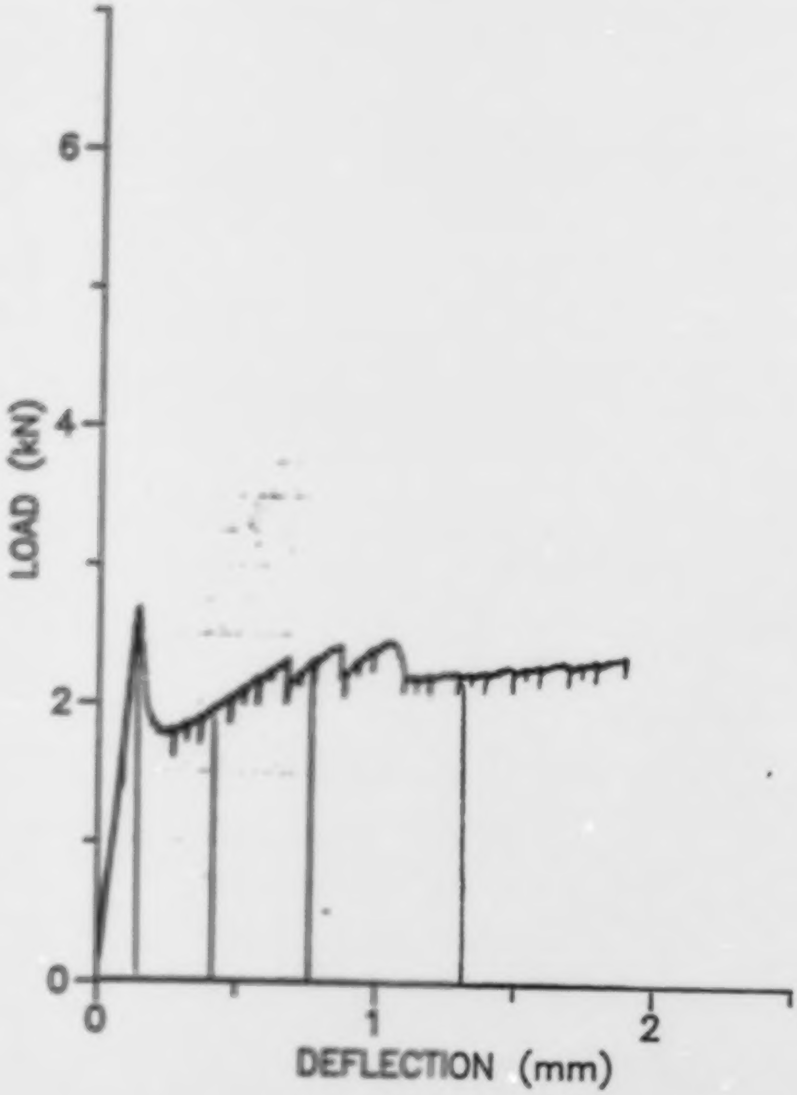
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: C4-2 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
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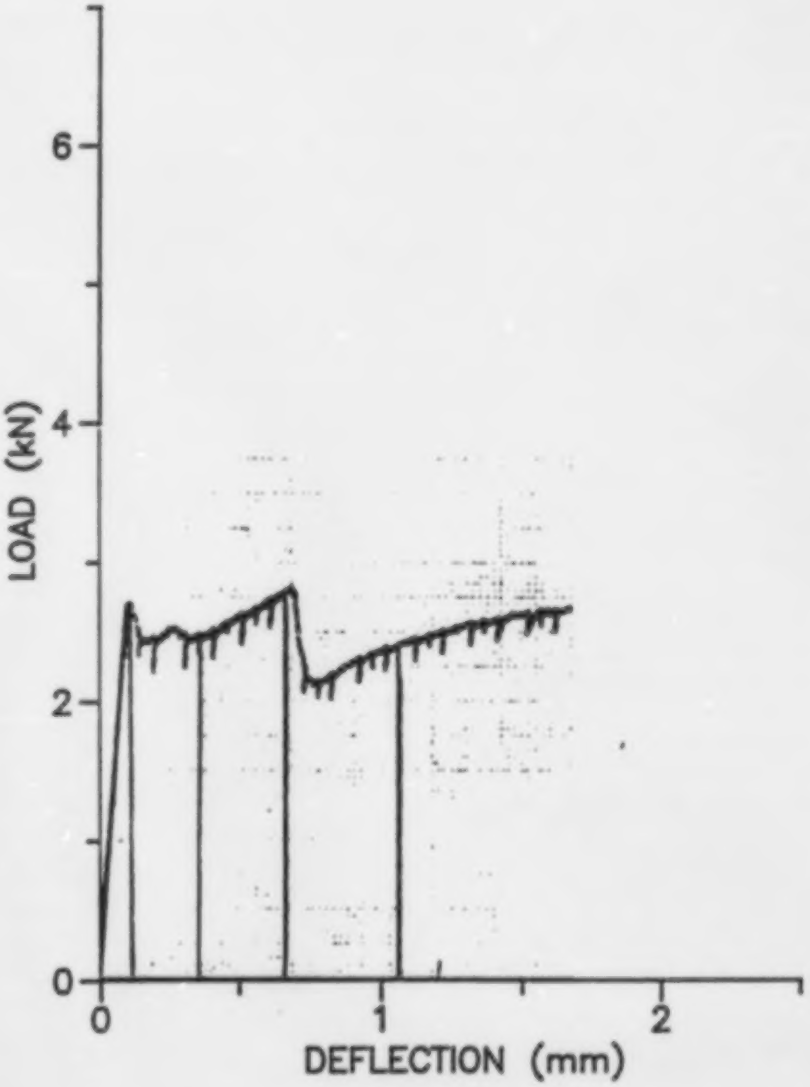
Scale	Date	Drawn By
N.T.S.	89-10-23	D.H.

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018–85

SPECIMEN NO.: C4–3 AGE OF TEST: 7 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.0 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

Scale	Date	Drawn By
N.T.S.	89–10–23	D.H.

APPENDIX C

PHASE I INVESTIGATIONS - HARDY BBT LTD.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

VA - 01584

November 29, 1989

Science and Professional Services Directorate
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
Hull, Quebec K1A 0S5

Attention: Mr. John Humphries

Dear Sirs:

Re: Phase I - Halifax Airport Cement/Fly Ash Sealant Evaluation
56 Day Compressive Strength Results

Hardy BBT Ltd. have completed 56 day compressive strength tests on the cement/fly ash based sealants from the Phase I testing program. The updated technical reports are enclosed.

This concludes the Phase I test program. The Phase II test program is presently underway. If you have any questions please call.

Yours truly,
Hardy BBT Limited.
Per: P. McGrath
P. McGrath, M.A.Sc., P.Eng.,
Materials Engineer

Reviewed By:
D.R. Morgan
D.R. Morgan, Ph.D., P.Eng.,
Chief Materials Engineer
PM:pm
✓ cc: Dr. V. Mohan Malhotra, Canmet

4052 GRAVELEY STREET, BURNABY, BRITISH COLUMBIA V5C 3T6 TELEPHONE (604) 294-3811 FAX (604) 294-4664 TELEX 04-354841
GEOTECHNICAL AND MATERIALS ENGINEERING — ENVIRONMENTAL, MATERIALS AND CHEMICAL SCIENCES
BONNYVILLE CALGARY EDMONTON FORT McMURRAY KAMLOOPS LETHBRIDGE LLOYDMINSTER MEDICINE HAT
PEACE RIVER PRINCE ALBERT PRINCE GEORGE RED DEER REGINA SASKATOON VANCOUVER

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT

TO: SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-11-22
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: A - Plain Control - No Fly Ash

MIX NO.	A1	AVG.	A2	AVG.	A3	AVG.	A4	AVG.
Compressive Strength, MPa @ 7 days	36.1, 36.1	36.7	38.4, 37.3	37.9	36.6, 38.2	37.4	34.7, 36.0	35.4
@ 28 days	44.2, 45.9	45.0	46.6, 47.1	46.9	47.4, 48.6	48.3	47.9, 48.6	48.3
@ 56 days	49.3, 50.8	50.1	48.4, 51.6	50.0	54.0, 54.8	54.4	52.3, 48.4	50.4
Flexural Strength, MPa @ 28 days	5.3,5.9,5.5	5.6	6.3,6.0,6.0	6.1	5.2,5.2,5.1	5.2	5.4,5.2,5.5	5.4
Toughness Index @ 28 days I_5	-	-	2.4,2.2,2.3	2.3	3.2,3.1,3.2	3.2	3.1,3.0,2.9	3.0
I_{10}	-	-	3.6,3.0,3.2	3.3	5.9,5.4,6.2	5.8	5.7,4.9,4.3	5.0
I_{20}	-	-	5.7,4.4,5.1	5.1	10.6, 9.6 11.3	10.5	9.8,8.4,7.0	8.4
Residual Strength, % RS(I_5, I_{10})	-	-	24, 16, 18	19	54, 46, 60	53	52, 38, 28	39
RS(I_{10}, I_{20})	-	-	21, 14, 19	18	47, 42, 51	47	41, 35, 27	34

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$
$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D. R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-11-22
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: B - 60% Fly Ash

MIX NO.	B1	AVG.	B2	AVG.	B3	AVG.	B4	AVG.
Compressive Strength, MPa								
@ 7 days	11.0, 10.4	10.7	9.9, 9.7	9.8	10.5, 10.3	10.4	10.9, 10.8	10.9
@ 28 days	21.0, 21.0	21.0	20.7, 20.5	20.6	22.0, 21.0	21.5	22.0, 20.7	21.4
@ 56 days	27.1, 24.4	25.8	26.9, 27.4	27.2	28.1, 26.2	27.2	26.9, -	26.9
Flexural Strength, MPa							*2.7	2.7
@ 28 days	2.8,2.8,2.9	2.8	2.6,2.7,2.7	2.7	3.1,3.1,2.9	3.0	2.6,2.9,2.8	2.8
Toughness Index @ 28 days								
I_5	-	-	2.6,2.6,2.6	2.6	3.5,3.8,3.3	3.5	3.4,3.7,3.9	3.7
I_{10}	-	-	3.8,4.3,3.7	3.9	6.7,7.2,6.3	6.7	6.8,7.6,7.7	7.4
I_{20}	-	-	6.0,7.3,5.9	6.4	12.6, 13.3 11.8	12.6	13.3, 14.6 14.2	14.0
Residual Strength, %								
$RS(I_5, I_{10})$	-	-	24, 34, 22	27	64, 68, 60	64	68, 78, 76	74
$RS(I_{10}, I_{20})$	-	-	22, 30, 22	25	59, 61, 55	58	65, 70, 65	67

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$

$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

2) *First crack flexural strength was less than the ultimate flexural strength.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE
Science Branch
11C1 Place Du Portage, Phase III
11 Laurier
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-11-22
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT.

SUBJECT: LABORATORY TRIAL MIXES - POLYPROPYLENE FIBRE REINFORCED HIGH-VOLUME FLY ASH WET-MIX SHOTCRETE; MIX PROPORTIONS AND PROPERTIES OF FRESH SHOTCRETE.
MIX DESIGNATION: C - 75% Fly Ash

MIX NO.	C1	AVG.	C2	AVG.	C3	AVG.	C4	AVG.
Compressive Strength, MPa								
@ 7 days	5.4, 5.2	5.3	5.0, 5.2	5.1	3.7, 3.7	3.7	7.2, 7.0	7.1
@ 28 days	12.1, 12.1	12.1	12.1, 12.2	12.2	8.9, 8.7	8.8	14.3, 14.6	14.5
@ 56 days	17.3, -	17.3	17.8, 17.3	17.6	13.6, 11.3	12.5	21.2, 19.7	20.5
Flexural Strength, MPa							*1.9 *1.9	1.9
@ 28 days	2.0,2.0,1.7	1.9	1.8,1.8,1.8	1.8	1.5,1.4,1.3	1.4	2.1,1.9,2.0	2.0
Toughness Index @ 28 days								
I_5	-	-	2.5,2.9,2.4	2.6	4.0,3.4,3.7	3.7	5.1,3.8,4.9	4.6
I_{10}	-	-	3.8,4.6,3.6	4.0	7.9,6.5,6.8	7.1	9.8,7.6,9.9	9.1
I_{20}	-	-	6.7,8.0,5.9	6.9	14.8, 12.4 12.1	13.1	17.2, 14.0 15.6	15.6
Residual Strength, %								
$RS(I_5, I_{10})$	-	-	26, 34, 24	28	78, 62, 62	67	94, 76, 100	90
$RS(I_{10}, I_{20})$	-	-	29, 34, 23	29	69, 59, 53	60	74, 64, 57	65

NOTE: 1) Residual strength is calculated as follows:

$$RS(I_5, I_{10}) = 20(I_{10} - I_5)\%$$

$$RS(I_{10}, I_{20}) = 10(I_{20} - I_{10})\%$$

2) *First crack flexural strength was less than the ultimate flexural strength.

TECHNICIAN: N. McAskill, A.Sc.T.
D. Hatch, A.Sc.T.

REPORT CERTIFIED: D.R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

ANNEX-2

REPORT ON PHASE II INVESTIGATIONS BY HARDY BBT LTD.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PHASE II REPORT ON DEVELOPMENT AND EVALUATION OF CEMENT/FLY ASH - BASED SEALANTS FOR CAPPING PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

PREPARED FOR
SCIENCE & SERVICES DIRECTORATE
SUPPLY AND SERVICES CANADA
HULL, QUEBEC

CONTRACT NO. 23440-8-9164/01-SQ
SSC FILE NO. 015SQ.23440-8-9164

BY
HARDY BBT LIMITED
BURNABY, B.C.

VA-01584
DECEMBER 22, 1989

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  - 2.1.2 Fly Ash
  - 2.1.3 Aggregates
  - 2.1.4 Superplasticizer
  - 2.1.5 Polypropylene Fibre
- 2.2 MIX DESIGNS
- 2.3 BATCHING, MIXING, SUPPLY, AND APPLICATION
- 2.4 PLASTIC SHOTCRETE PROPERTIES
- 2.5 COMPRESSIVE STRENGTH
- 2.6 FLEXURAL STRENGTH AND TOUGHNESS INDEX
- 2.7 BOILED ABSORPTION AND PERMEABLE VOIDS
- 2.8 AIR VOID PARAMETERS
- 2.9 FREEZING AND THAWING DURABILITY
- 2.10 RESTRAINED SHRINKAGE TEST
- 2.11 WATER PERMEABILITY

3.0 CONCLUSIONS

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APPENDIX B - ADDITIONAL TECHNICAL REPORTS
APPENDIX C - FLEXURAL STRENGTH DATA
APPENDIX D - PRODUCT LITERATURE

1.0 INTRODUCTION

Hardy BBT Limited are pleased to submit the Phase II Report on Development and Evaluation of Cement/Fly Ash - Based sealants for Capping Pyritic Slate outcrops at Halifax Airport. The terms of reference of this study are detailed in the Supply and Service Contract No. 23440-8-9164/01-SQ. This report presents the results of the Phase II study up to and including the 28 day test data.

1.1 BACKGROUND

This study evolved from the need to provide a mitigative solution to the problem of acid leachates from exposed pyritic slates at the Halifax airport. This pyritic slate is susceptible to breakdown from exposure to the atmosphere and penetrating rain and surface waters. Bacterial attack of the slate and other chemical processes have led to the generation of leachates which are highly acidic and carry with them heavy metals and other potentially toxic elements. The release of these contaminants into the local ground water system has serious environmental implications.

One of the possible control measures available is the reduction of the penetration of surface water into the slate outcrop. This study focuses on the material properties of one of the possible capping systems - high volume fly ash/portland cement shotcrete with integral high volume fibrillated polypropylene fibre reinforcement (PFRS). The Phase I portion of the study evaluated a broad range of laboratory trial mix designs from which the most promising mixes were identified for the full scale shotcrete test program in Phase II. Some of the key items that will be commented on in this Phase II Report are as follows:

- Low water permeability - effectiveness of the capping material is evaluated based on the water permeability of the shotcrete matrix, as well as its resistance to shrinkage cracking as evaluated in restrained shrinkage tests.

- Long term durability - Resistance of the capping material to cycles of freezing and thawing is being tested directly by laboratory testing to ASTM C666 and field exposure, while qualitative assessments are made based on overall strength, and ductility. CANMET will be further assessing the quality of the shotcrete in assessment of the characteristics of the air void system and water permeability.

- Ductility - the ability of the capping material to resist tearing, cracking, or damage from stresses and deformations typical in this application is evaluated based on flexural strength and toughness index parameters.

- Chemical resistance to seeping leachates - no specific testing has been conducted but qualitative statements are presented based on boiled absorption and permeable void tests.

- Commercial viability - comments are made regarding the ease of producing and installing the capping material.

1.2 SCOPE OF WORK

The scope of work conducted in the Phase II Study was set out in Appendix A of the Contract Document and in subsequent communications with CANMET.

Based on the results of Phase I and on complementary investigations carried out at CANMET, six mixes were selected for full scale shotcreting and fabrication of shotcrete test panels. The principle mix variables are:

- two cementitious contents
- three addition rates of polypropylene fibres: 0%, 3%, and 6%

Two large test panel assemblages were fabricated and shotcreted for restrained shrinkage testing by Hardy BBT. One test panel has a fully bonded bedding while the other has unbonded bedding to represent the range of bedding conditions found at the Halifax airport. The panels are presently being subjected to exposure to normal outdoor

Vancouver weather. The specimens are to be monitored periodically for crack size, pattern and spacing, and general weathering performance.

Smaller shotcrete test panels were fabricated from which specimens were procured for determining the following properties of the hardened shotcrete:

- Compressive strength testing on 75 mm diameter cores at ages of 7, 28 and 56 days. In addition shotcrete cylinders, were made by shooting into 150 x 300 mm cylinder moulds. These cylinders are being tested at the same ages as the 75 mm cores for direct comparison of the two methods of fabricating compressive strength specimens.

- Prisms, (75 x 75 x 355 mm), for determination of flexural strength, and ASTM C1018 Toughness Index Parameters, (I_5, I_{10}, and I_{20}), at an age of 28 days.

- 75 x 90 x 405 mm prisms were saw cut for testing in accordance with ASTM C666 Resistance of Concrete to Rapid Freezing and Thawing (Procedure A). Specimens were placed in the Logan freeze/thaw test unit at an age of 28 days.

- 75 mm cubes were tested according to ASTM C642 Specific Gravity, Absorption and Voids in Hardened Concrete.

- 150 mm diameter cores have been shipped to CANMET for testing for water permeability and air void parameters of the hardened shotcrete.

2.0 TEST PROGRAM AND RESULTS

2.1 SHOTCRETE MATERIALS

2.1.1 Portland Cement

The portland cement used in this study was supplied by St. Lawrence Cement from Beauport, Quebec and conforms to the requirements of CAN/CSA-A5-M88 for a Type 10 portland cement. Typical physical and chemical properties of the cement are given in Table 1 in Appendix A.

2.1.2 Fly Ash

A low calcium fly ash conforming to CAN/CSA-A23.5-M86 Type F was used in this study. The fly ash is a waste product from a thermal generation plant at Lingan, Nova Scotia and is marketed for use in concrete by Nova Scotia Sand & Gravel. Typical physical and chemical properties of the fly ash are given in Table 2 in Appendix A.

2.1.3 Aggregates

The aggregates used in this study were supplied by Target Products Limited of Burnaby, British Columbia. These aggregates are routinely used in shotcrete production in Western Canada and have proven acceptable performance in concrete and shotcrete in exterior exposure conditions. Gradation analyses of the 10 mm coarse aggregate fraction, and shotcrete sand are given in the appended Technical Reports #B1 and #B2 respectively in Appendix B. The aggregate was combined so that the coarse aggregate was 30 % by mass of the total combined aggregate. The combined aggregate gradation is shown in Technical report #B3 in Appendix B. Note that the combined aggregate falls just outside the fine side of the ACI 506R-85, Table 2.1, Gradation No. 2 envelope on the 1.25 mm and 630 mm sieves, but this is undesirable for high volume polypropylene fibre reinforced shotcretes.

2.1.4 Chemical Admixtures

The superplasticizer used was "DURASAR" supplied by Handy Chemicals Limited of La Prairie, Quebec. It is a naphthalene sulphonate calcium salt. Product literature and typical physical property data are given in Appendix D. It is understood that "DURASAR" conforms to the requirements of CAN3-A266.6-M85 Superplasticizer Admixtures for Concrete. No additional water reducing admixtures were added to the mixes.

2.1.5 Polypropylene Fibre

The fibre used in this study was 38 mm long "FORTA CR" twisted, fibrillated, polypropylene fire, supplied by Elsro Construction Products, St. Albert, Alberta. The fibre is manufactured by the Forta Corporation of Grove City, Pennsylvania, U.S.A. Product literature is included in Appendix D.

2.2 SHOTCRETE MIX DESIGNS

A summary of the as batched mix proportions, used in the test program, is given in Technical Report #A1 in Appendix A. Detailed yield analyses of the mixes based on as-batched quantities are given in Technical Reports #B4 to #B9 in Appendix B.

Mixes U, V, and W have a total cementitious content in the range of 418 to 430 kg/m^3 of which 63% is fly ash and mixes X, Y and Z have a total cementitious content in the range of 471 to 487 kg/m3 of which 64% is fly ash. The Phase I report recommended a minimum cement content of 400 kg/m^3. Water to cementitious materials ratios ranged from 0.29 to 0.36 with one outlier at 0.25 (Mix U).

The sand content is 70% of the total aggregate mass, which is typical for wet mix polypropylene fibre reinforced shotcrete.

2.3 BATCHING, MIXING, SUPPLY, AND APPLICATION

The fly ash, cement and dry aggregates were weigh batched and prebagged in bulk bin bags by Target Products. Mixing water was weighed by placing a "45 gallon drum" on a 225 kg scale. The estimated water demand was corrected for absorption of the as-batched aggregate masses and approximately 2/3 this water was pumped into a transit mix truck followed by the dry materials which were discharged into the mixer with a high-lift forklift. Most of the remaining estimated water requirement was added followed by addition of the DURASAR superplasticizer and the air entraining admixture. The mixture was allowed to mix thoroughly by rotating the transit mixer drum at full mixing speed. Slump was measured and water was added until the required initial slump was achieved. Air content was measured and adjusted upwards if necessary. The required amount of fibre was added and slump and air were measured again. Additional water was added as necessary to produce the required workability for pumping and shooting. All water additions were recorded.

Mix U, a plain control mix without any fibre addition, was the first mix batched. DURASAR superplasticizer was added to this batch at a high addition rate of 9.5 l/m^3. This mixture had a water demand of only 108 l/m^3 and enabled the assessment of "extreme" water reduction on the pumpability and shootability of a plain shotcrete. While this shotcrete was at flowing consistency (220 mm slump), it was very sticky and cohesive. Pump pressures were excessive and the mixture proved very difficult to shoot through a 50 mm I.D. hose. By changing to a 63 mm I.D. hose, it was possible to adequately shoot the required test panels. The mixture was, however, judged to be "water-starved" and not suitable for use with high volume polypropylene fibre additions. Consequently it was decided to use lower superplasticizer addition rates in all the remaining mixes.

The remaining mixes, V through Z, had DURASAR superplasticizer added at addition rates varying between 4.2 and 5.2 l/m^3. (see Technical Report A1 in Appendix A). The water demand for these mixtures varied between 142 and 158 l/m^3 and the water/cementitious ratio between 0.29 and 0.36. These mixtures were judged to have suitable plastic properties for pumping and shooting.

All the mixtures were shot through the 63 mm I.D. flexible hose. Prior to shooting the mix the lines were cleared of the previous mix until a steady stream of the new mix was obtained. Restrained shrinkage panels were shot first followed by the smaller test panels and the moulded shotcrete test cylinders.

2.4 PLASTIC SHOTCRETE PROPERTIES

A summary of the plastic shotcrete properties is given in Technical Report A2 in Appendix A. Slump and air content were measured before and after the addition of fibres. Air content of the in place shotcrete was measured by directing the stream of shotcrete from the nozzle into the air meter base.

The following are comments with respect to the pumping and shooting characteristics of the different mixtures:

> As previously mentioned, Mix U appeared "water starved" and was excessively cohesive and sticky, and difficult to shoot and finish in spite of being at a flowing consistency (220 mm slump). Mixtures V, W, X, Y, and Z all had suitable pumping and shooting characteristics. There was, however, a slight tendency to segregation in the high polypropylene fibre shotcrete mixtures W and Z with some of the coarser aggregate particles being "thrown-out" on the surface of the restrained shrinkage test panels. This, together with more fibres at the surface of these mixtures, made finishing with a bull float more difficult. This was, however, not judged to be a major concern.

All the mixtures were batched with air contents in the range of 8.8 to 12.6 percent before fibre addition. (See Technical Report A2 in Appendix A). The air content of the mixes "as shot" into an air pressure meter base varied between 3.6 and 5.2 percent. It is apparent that a substantial amount of air was lost in the pumping and shooting operation. The air void parameter testing to be conducted by CANMET should provide information concerning the "quality" of the in-place air content ie. are the spacing factor and specific surface adequate for freeze/thaw durability considerations.

2.5 COMPRESSIVE STRENGTH

Standard test panels were produced by shooting into wooden forms. These wooden forms were 600 x 600 x 125 mm and had 45° sloped sides. The panels were covered with polyethylene and left in the cool outdoor environment (3 to 10°C) for the first 6 days of curing in order that they would develop sufficient strength to withstand damage during transport to the laboratory. Following that, panels were moist cured at 23°C in a fog room until the time of testing.

Cores 75 mm diameter x 100 mm long were diamond drilled at age 6 days for 7 day compressive strength specimens and at 24 days for 28 day compressive strength specimens. The specimens (two per mix) were trimmed, capped and tested to CSA A23.2-14C procedures. A summary of the average compressive strength of the two cores at 7 and 28 days is shown in Technical Reports #A3 and #A4 in Appendix A.

There are a complex set of variables influencing compressive strength. These include cementitious content, cement/fly ash ratio, water demand (and hence water/cementitious ratio), air content and polypropylene fibre content. Overall, however, the strongest correlation exists between compressive strength and water/cementitious ratio, with the lower water/cementitious ratio mixes displaying the highest compressive strengths. This is well illustrated in Figure 1 in Appendix A.

Also included in Technical Reports #A3 and #A4 are the 7 and 28 day compressive strength results from the 150 x 300 mm moulded shotcrete cylinders. The results show a good correlation between the strength of cored cylinders and moulded shotcrete cylinders, see Figure 2 and Figure 3. The moulded shotcrete cylinders tended to have slightly lower compressive strengths than the shotcrete cylinders at 28 days, but this trend was not obvious at 7 days. The moulded shotcrete cylinders also showed good repeatability between replicate specimens. However, this was only after approximately 10% of the specimens were rejected because of large voids. Such cylinders were easily identified and were not tested. It is believed that these voids resulted from slight deviations from vertical of the angle of the shotcrete nozzle relative to the cylinder moulds at the time of shooting.

2.6 FLEXURAL STRENGTH AND TOUGHNESS INDEX

Prisms, 75 x 75 x 355 mm, were saw cut for determination of flexural strength in accordance with CSA A23.2-8C, and ASTM C1018 I_5, I_{10}, and I_{20} toughness index parameters after 6 days of field curing followed by 22 days of moist curing at 23 °C. The tests were conducted on a 100 kN servo controlled MTS testing machine. Deflection was measured with a pair of averaging LVDT's. The test results are given in Technical Reports #A3 and #A4 in Appendix A. Load verses deflection data was recorded on a strip chart recorder and the plots are included in Appendix C.

Toughness indexes (I_5, I_{10}, and I_{20}) and residual strengths were calculated based on the output of the load verses deflection data in accordance with ASTM C1018. A common toughness index specification for fibre reinforced shotcretes used in tunnelling, mining, slope stabilization and remedial works is:

$$I_5 \geq 3.5$$
$$I_{10} \geq 5.0$$

Mix Z, containing 6.5 % fibres and 470 kg/m^3 cementitious was the only mix to meet both these requirements. Mix V failed to meet either of these criteria. Mixes Y and W met the above I_{10} limits and nearly met the I_5 limits.

2.7 BOILED ABSORPTION AND PERMEABLE VOIDS

The boiled absorption, volume of permeable voids and bulk relative density of the 6 shotcrete mixes was determined according to the ASTM C642 test procedure. Three 75 mm cubes were cut from the ends of the flexure specimens after 28 day tests were complete and were returned to the fog room until testing at an age of 35 days. Results of the testing are shown in Technical Reports #A3 and #A4 in Appendix A. Results of the tests are consistent with expected behaviour and in all cases indicate dense, well consolidated mixtures. Using rating criteria commonly used in the shotcrete industry in Canada, Mixes U, X, and Y would be considered to be of "excellent" quality and Mixes V, W, and Z, of "good" quality. In ranking the performance of the different mixtures there is good correlation between water/cementitious ratio, compressive strength and values for boiled absorption and volume of permeable voids. This is well illustrated in Figure 1 and Figure 4 in Appendix A.

2.8 AIR VOID PARAMETERS

Cores, 150 mm in diameter, for testing of air void parameters were diamond drilled from the small shotcrete test panels at an age of 24 days and sent to CANMET's Ottawa laboratory for testing. Tests will be conducted to determine spacing factor, hardened air content and specific surface in accordance with ASTM C457 Modified Point Count Method.

2.9 FREEZING AND THAWING DURABILITY

The shotcrete test panels were cured in the field for 6 days and then moist cured in the fog room for a further 16 days. At 23 days after shooting, three prism samples, 75 x 90 x 405 mm were saw cut from the small shotcrete test panel. These prisms were cured in water at 23°C until freeze/thaw testing commenced at 28 days. Freeze/thaw testing is being conducted to ASTM C666 (Procedure A) in a Logan Freeze/thaw test unit to 300 cycles.

The testing will include measurement of fundamental transverse frequency and mass change. Results of the testing will be reported when complete.

2.10 RESTRAINED SHRINKAGE TEST

Two large test panel assemblies were constructed for restrained shrinkage testing, see Figure 5. Shotcrete was applied to a depth of 40 mm over a bedding of Halifax Airport shale in the 1.0 x 3.0 metre steel forms. Two panels were prepared for each of the six mixes. The first panel represents an unbonded situation and has a bedding of small fragments of shale (< 20 mm), compacted with a plate tamper and screeded smooth. The second panel has a bedding of larger slate pieces set firmly into a cement mortar base (approximately 70% of the surface is exposed slate) and represents a fully bonded situation. It is thought that this will cover the extremes of bedding conditions prevalent at the Halifax airport. Each panel is restrained from movement at the long end by a reinforcing steel grid, dowelled into the bulkhead and free to move along the other two side walls, resulting in unidirectional shrinkage stresses.

The panels were protected from the rain for the first 7 days after shooting, by a tented tarpaulin structure, but otherwise have been continuously exposed to the outdoor environment since the time of casting. Observations were made at ages of 1, 4 and 28 days. To this date no shrinkage cracking has been observed in any of the panels. There has, however, been a substantial amount of precipitation during this period and thus only limited opportunity for drying.

2.11 WATER PERMEABILITY

Two cores, 150 mm in diameter by 125 mm long, were diamond drilled from the small shotcrete test panels, from each of the six shotcrete mixes, at an age of 24 days. The test samples were wrapped in plastic and sent to CANMET's Ottawa laboratory for testing of water permeability.

3.0 CONCLUSIONS

1) This Phase II evaluation has demonstrated that it is possible to batch, mix, pump and shoot high volume fly ash, high volume polypropylene fibre reinforced wet mix shotcrete mixtures in the field, using conventional transit mix supply and wet-mix shotcrete equipment, provided the mixtures are properly designed.

2) The mixtures require a certain minimum amount of water in order to be suitable for practical field application. In Mix U a high dosage of superplasticizer was used and the water content was reduced to 108 l/m^3. This mixture, in spite of being at a flowing consistency, was too cohesive and sticky for practical field application. The water content in all the other mixtures tested was increased to be in the range of 142 to 158 l/m^3.

3) The 38 mm long FORTA CR twisted collated, fibrillated, polypropylene fibre used in this study could be readily added, mixed and dispersed by direct addition to a transit mixer. The mixtures pumped and shot well at fibre addition rates of around 3.5 kg/m^3 with no evidence of segregation or fibre balling. At higher fibre addition rates of around 6.5 kg/m^3 the mixtures were still suitable for pumping and shooting, but there was a slight tendency to segregation, with coarse aggregate particles being "thrown-out" onto the surface of the consolidated shotcrete during shooting of the large restrained shrinkage test panels. This was not viewed as a major concern, and a slight reduction in the coarse aggregate fraction and/or fibre content would tend to offset this effect.

4) Compressive strength of the leaner mixtures (nominal 420 kg/m^3 cementitious content) was around 18 to 19 MPa at 28 days on cores extracted from test panels. The richer mixtures (nominal 480 kg/m^3 cementitious content) had 28 day compressive strengths in the range of 19 to 23 MPa. There was a good correlation between water/cementitious ratio and compressive strength. Higher 28 day compressive strengths are attainable through the use of higher dosages of superplasticizer (Mix U had a 28 day compressive strength 38 MPa). Pumping and

shooting requirements, however, place a limit on the amount of superplasticizer that can be practically used, as noted in Item 2.

5) Flexural strength generally followed the same trends as compressive strength. The best ASTM C1018 toughness index performance was attained with the rich mix (Mix Z) with 6.5 kg/m^3 polypropylene fibre. This mix met the commonly specified toughness index requirements of $I_5 \geq 3.5$ and $I_{10} \geq 5.0$. The rich mix (Mix Y) with 3.3 kg/m^3 polypropylene fibre came close to meeting these requirements. The lean mix (Mix V) with 3.1 kg/m^3 polypropylene fibre failed to meet either of the above toughness index limits.

6) Boiled absorption and permeable voids testing showed that virtually all the shotcrete was well consolidated and dense. There was a good correlation between water/cementitious ratio and the values of boiled absorption and permeable voids, with the lowest water/cemetitious ratio mixtures (which had the highest compressive and flexural strengths) showing the lowest values for boiled absorption and permeable voids. Values obtained placed the shotcrete in either an "excellent" or "good" category, according to commonly accepted criteria for rating these qualities of shotcrete.

7) Large restrained shrinkage test panels were fabricated. Two restraint conditions were evaluated; shotcrete applied to slate bedded in a mortar and shotcrete applied to a loose slate. The test panels were exposed to Vancouver weather and at up to one month after fabrication no shrinkage cracks had appeared in any of the test panels. There was a considerable amount of precipitation during this period and the panels have to date experienced only limited drying. They will continue to be monitored over the next year and any cracking which develops will be reported. The panels will also enable resistance to weathering in a Vancouver winter to be monitored. (See note below).

8) Freeze/thaw testing to ASTM C666 Procedure commenced at age 28 days after shooting. This testing will be continued for 300 freeze/thaw cycles and test results will be reported when the testing is completed. 56 day compressive strength tests are also still outstanding and will be reported when available. (See note below).

9) Specimens cut from test panels for each of the six shotcrete mixtures have been shipped to CANMET in Ottawa for water permeability testing and evaluation of the parameters of the air void system. (See note below).

In conclusion, the results of the testing completed to date look very encouraging. A final report will be issued once the 56 day compressive strength and freeze/thaw test results are available. Recommendations for final mixture designs for use in the Halifax Airport project will be provided in the final report. (See note below).

Respectfully Submitted,
Hardy BBT Limited

Per: P. McGrath

P. McGrath, M.A.Sc., P.Eng.
Materials Project Engineer

Per: D. R. Morgan

D.R. Morgan, Ph.D., P.Eng.
Chief Materials Engineer

Reviewed by: Jim Neill.

J. Neill, P.Eng.
Materials Engineer

PMcG:DRM:nlg

Note: Additional data obtained in this phase of the studies including recommendations for final mixture design are given in Appendix E.

APPENDIX A

PHASE II INVESTIGATIONS - HARDY BBT LTD.

TABLE 1

**ST. LAWRENCE
CEMENT**

1300 Ste. Anne Boulevard
Beauport, Quebec
P.O. Box 1150
Quebec, Quebec
G1K 7C9

Telephone (418) 663 7831
Telecopier (418) 663-8741
Telex 051 3009 (Laurencim Qbc)

CEMENT TEST REPORT

PERIOD July 1989

SAMPLE DESIGNATION TYPE 10 MARITIMES

CHEMICAL ANALYSIS		PHYSICAL PROPERTIES	
Loss on ignition	1.44 %	Fineness :	
Insoluble residue	0.36 %	Blaine	3935 cm^2/kg
Free lime	0.92 %	Passing 45 micro	94.42
		Setting time :	
Silica (SiO_2)	21.09 %	Initial	155 min.
Alumina (Al_2O_3)	4.81 %	Final	305 min.
Iron oxide (Fe_2O_3)	2.33 %	Soundness :	
Calcium oxide (CaO)	62.32 %	Autoclave expansion	0.13 %
Magnesia (MgO)	3.06 %	Air content	7.5 %
Sulphur trioxide (SO_3)	3.01 %	False set	86.7 %
Alkalis (Na_2O equivalent)	0.88 %		
		Compressive strength :	
Mineralogical composition :			
Tricalcium silicate (C_3S)	49 %	at 3 days	25.0 MPa
Dicalcium silicate (C_2S)	23 %	at 7 days	32.6 MPa
Tricalcium aluminate (C_3A)	8.8 %	at 28 days	N/A MPa
Ferro-Aluminate (C_4AF)	7.1 %		

Above results indicate that the cement represented by this sample complies with all requirements of specification CAN/CSA-A5-M88.

28 days for June 89: 38.0 MPA

Beauport, August 15, 1989

Rene Cossette, eng.
Colin Danylo, eng.
Chief Chemist

TABLE 2 - CHEMICAL AND PHYSICAL PROPERTIES OF LINGAN LOW CALCIUM FLY ASH

CHEMICAL COMPOSITION	PERCENT BY MASS
SiO_2	45.2
Al_2O_3	20.7
Fe_2O_3	24.8
CaO	1.63
MgO	0.97
TiO_2	1.05
SO_3	0.65
K_2O	2.40
Na_2O	0.59
PHYSICAL TESTS	**TEST RESULTS**
Loss on Ignition (%)	2.66
Pozzolanic Activity Index (with cement) (%)	97
Blaine Fineness (m^2/kg)	351
Percent Finer Than 45 um	84
Relative Density	2.64

Hardy BBT Limited
[illegible]

TECHNICAL REPORT #A1

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-12-14
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MIX NO.	U	V	W	X	Y	Z
Fibre Dosage, kg/m3 FORTA CR-38 mm	0	3.1	6.4	0	3.3	6.5
Type 10 Cement, kg/m3	161	157	158	172	174	167
Fly Ash, kg/m3	269	261	264	312	313	303
10 x 5 mm Coarse Aggregate (SSD), kg/m3	541	520	520	507	500	489
Sand (SSD), kg/m3	1267	1220	1223	1198	1185	1159
Water 1/m3	108	152	149	147	142	158
Superplasticizer, 1/m3 DURASAR	9.5	5.2	4.2	4.3	4.4	4.3

Hardy BBT Limited

TECHNICAL REPORT #A2

TO: SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-14
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

SUBJECT: PLASTIC SHOTCRETE PROPERTIES FOR PHASE II FIELD SHOTCRETE STUDY

MIX NO.	U	V	W	X	Y	Z
W/C + FA Ratio	0.25	0.36	0.35	0.30	0.29	0.34
Slump Before Fibre Addition, mm	220	60	135	120	115	230
Air Content Before Fibre Addition, %	9.3	10.7	12.6	9.7	8.8	12.5
Slump After Fibre Addition, mm	-	45	40	-	55	125
Air Content After Fibre Addition, %	-	10.0	9.6	-	10.8	13.7
Air Content, % (after shooting)	5.2	3.9	3.6	3.6	4.5	4.5
Ambient Temperature, °C	8	5	3	7	-	10
Shotcrete Temperature, °C	12	13	12	14	14	13

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #A3

TO:
SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 90-01-11
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

SUBJECT: FIELD TRIAL MIXES, POLYPROPYLENE FIBRE REINFORCED HIGH VOLUME FLY ASH WET-MIX SHOTCRETE; TEST RESULTS; NOMINAL 420 kg/m3 CEMENTITIOUS

MIX NO.	U	AVG.	V	AVG.	W	AVG.
Compressive Strength 75 mm Ø Core (MPa)						
@ 7 days	18.3, 17.0	17.7	7.1, 6.8	7.0	5.4, 6.8	6.1
@ 28 days	38.1, 37.6	37.9	19.5, 18.5	19.0	18.6, 17.7	18.2
@ 56 days	45.0, 44.6	44.8	21.2, 21.3	21.3	22.1, 23.0	22.6
Compressive Strength 150 mm x 300 mm Cylinders (MPa)						
@ 7 days	15.8, 16.0	15.9	6.3, 7.3	7.3	8.0, 7.8	7.9
@ 28 days	34.3, 30.0	32.2	17.4, 16.8	17.1	16.5, 17.2	16.9
@ 56 days	35.1, 39.8	37.5	20.1, 21.5	20.8	19.8, 21.1	20.5
Flexural Strength, MPa @ 28 days	5.0,4.9,4.5	4.8	2.9,2.9,2.8	2.9	2.6,2.8,2.7	2.7
Toughness Index @ 28 days						
I_5	-	-	2.7,3.0,2.8	2.8	3.1,3.1,3.9	3.4
I_{10}	-	-	4.9,4.8,4.9	4.9	5.8,5.5,7.0	6.1
I_{20}	-	-	8.7,7.8,8.1	8.2	11.0, 9.7, 11.2	10.6
Residual Strength, %						
$RS(I_5, I_{10})$	-	-	44, 36, 42	41	54, 48, 62	55
$RS(I_{10}, I_{20})$	-	-	38, 30, 32	33	52, 42, 42	45
Boiled Absorption, %	3.4,3.3,3.4	3.4	6.3,6.2,6.3	6.3	6.7,7.7,6.8	7.1
Permeable Voids, %	7.9,7.7,7.8	7.8	13.9, 13.5 13.9	13.7	14.5, 16.2 14.5	15.1

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #A4

TO:

SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 90-01-11
CLIENT P.O.
C.C.

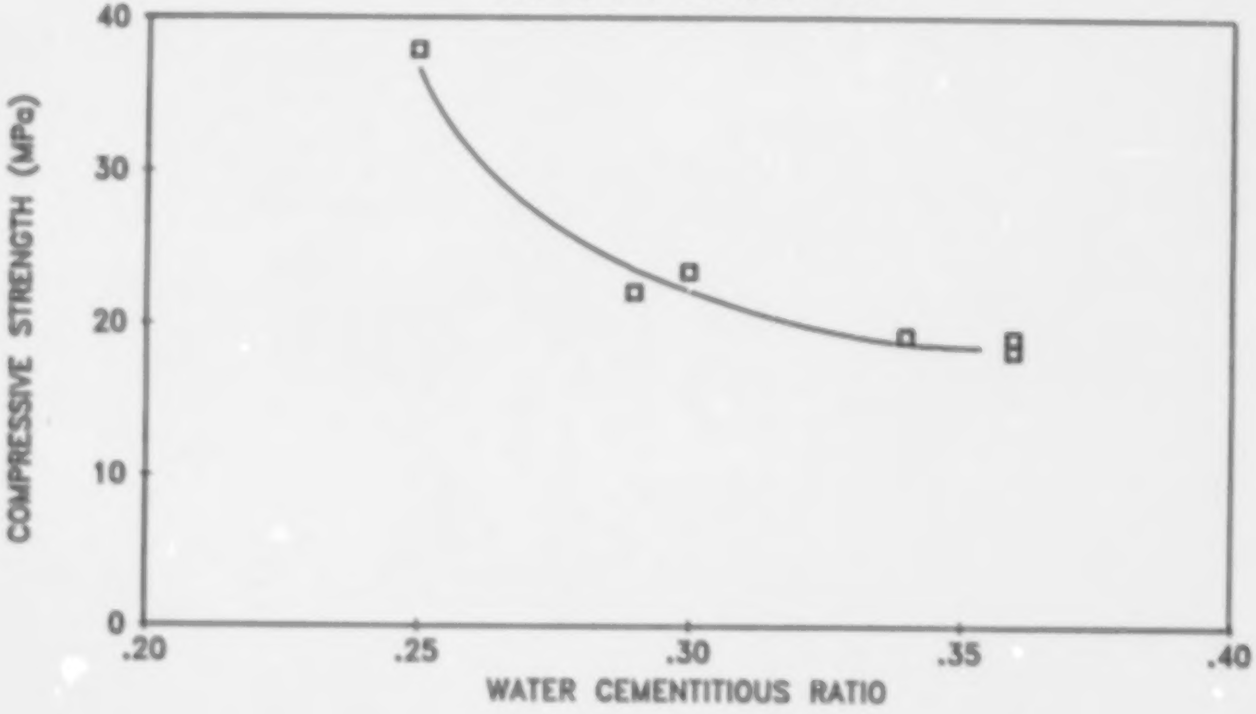
PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

SUBJECT: FIELD TRIAL MIXES, POLYPROPYLENE FIBRE REINFORCED HIGH VOLUME FLY ASH WET-MIX SHOTCRETE; TEST RESULTS; NOMINAL 480 kg/m3 CEMENTITIOUS

MIX NO.	X	AVG.	Y	AVG.	Z	AVG.
Compressive Strength 75 mm Ø Core (MPa)						
@ 7 days	10.4, 10.0	10.2	9.4, 8.1	8.8	7.4, 7.8	7.6
@ 28 days	22.8, 24.0	23.4	21.5, 22.6	22.1	18.7, 19.7	19.2
@ 56 days	25.3, 29.2	27.3	25.6, 25.6	25.6	24.8, 22.3	23.6
Compressive Strength 150 mm x 300 mm Cylinders (MPa)						
@ 7 days	9.8, 9.7	9.8	9.4, 9.3	9.4	6.9, 6.8	6.9
@ 28 days	26.9, 21.7	24.3	20.0, 20.3	20.2	15.5, 16.1	15.8
@ 56 days	23.3* 23.6*	23.5	24.3, 25.2	24.8	20.0, 18.5	19.3
Flexural Strength, MPa @ 28 days	3.4,3.4,2.9	3.2	3.4,3.1,3.1	3.2	3.3,2.7,3.3	3.1
Toughness Index @ 28 days						
I_5	-	-	3.0,3.5,3.6	3.4	3.8,3.9,3.5	3.7
I_{10}	-	-	5.4,6.1,6.1	5.9	7.8,7.5,6.4	7.2
I_{20}	-	-	9.1, 11.0, 10.4	10.2	12.8, 13.9 11.8	12.8
Residual Strength, %						
$RS(I_5, I_{10})$	-	-	48, 52, 50	50	80, 72, 58	70
$RS(I_{10}, I_{20})$	-	-	37, 49, 43	43	50, 64, 54	56
Boiled Absorption, %	5.1,5.1,5.4	5.2	6.1,5.4,5.8	5.8	6.7,6.8,6.6	6.7
Permeable Voids, %	11.5, 11.5 11.9	11.7	13.3, 12.1 12.9	12.7	14.5, 14.7 14.4	14.5

*Voids of incomplete consolidation in cylinders.

RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH OF 75 mm DIAMETER CORES AND WATER/CEMENTITIOUS RATIO



REVISIONS

REFERENCES

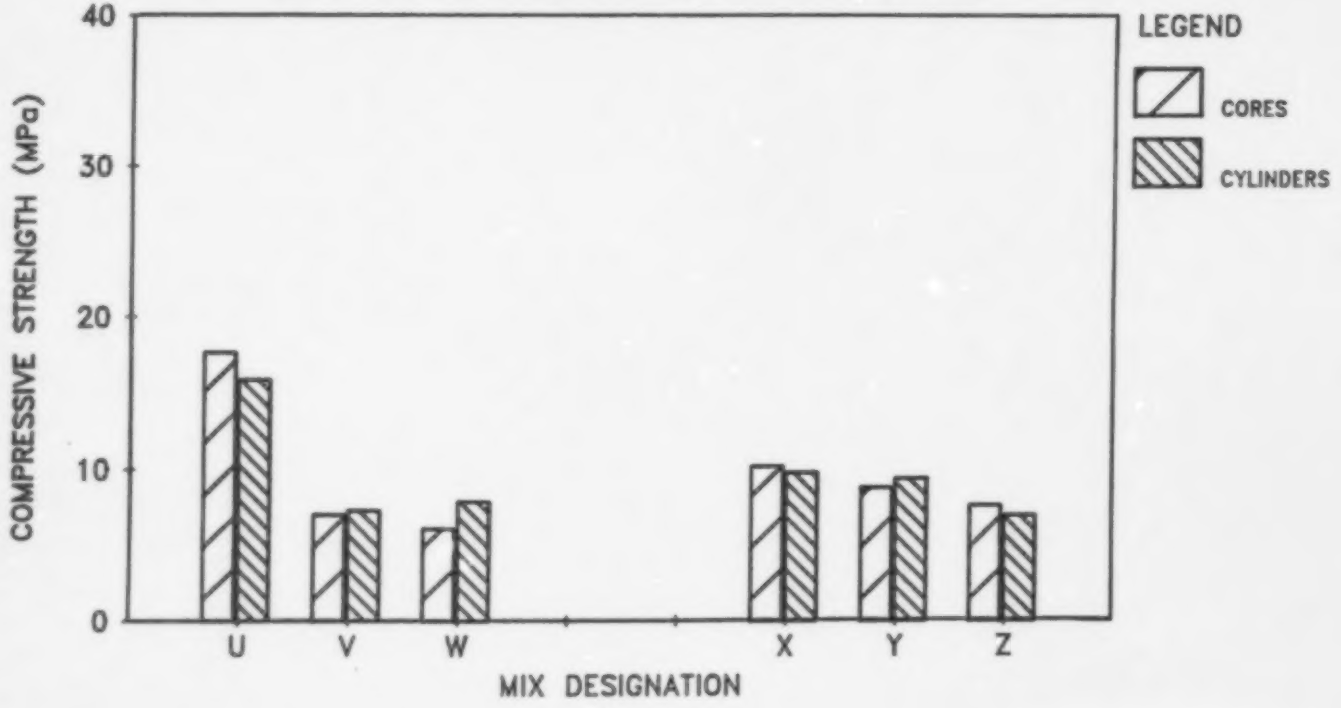
[redacted]

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

FIGURE 1

SCALE [redacted] DATE [redacted] MADE [redacted] CHKD [redacted] No [redacted] FIGURE [redacted]

COMPARISON OF 7 DAY COMPRESSIVE
STRENGTH OF 75 mm DIAMETER CORES TO
150 X 300 mm MOULDED SHOTCRETE CYLINDERS



REVISIONS

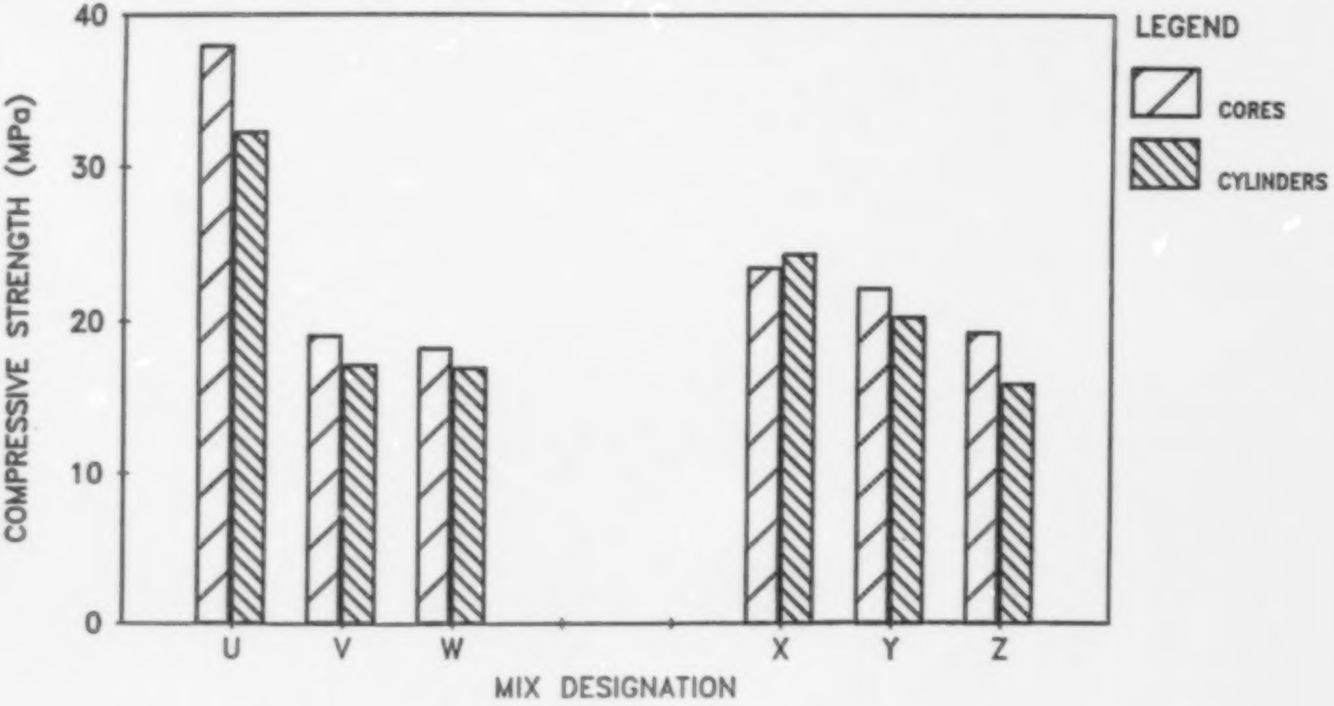
REFERENCES

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

FIGURE 2

SCALE	DATE DEC 18/89	MADE P.Mc	CHKD	JOB No. VA 01584	FIGURE

COMPARISON OF 28 DAY COMPRESSIVE
STRENGTH OF 75 mm DIAMETER CORES TO
150 X 300 mm MOULDED SHOTCRETE CYLINDERS



REVISIONS

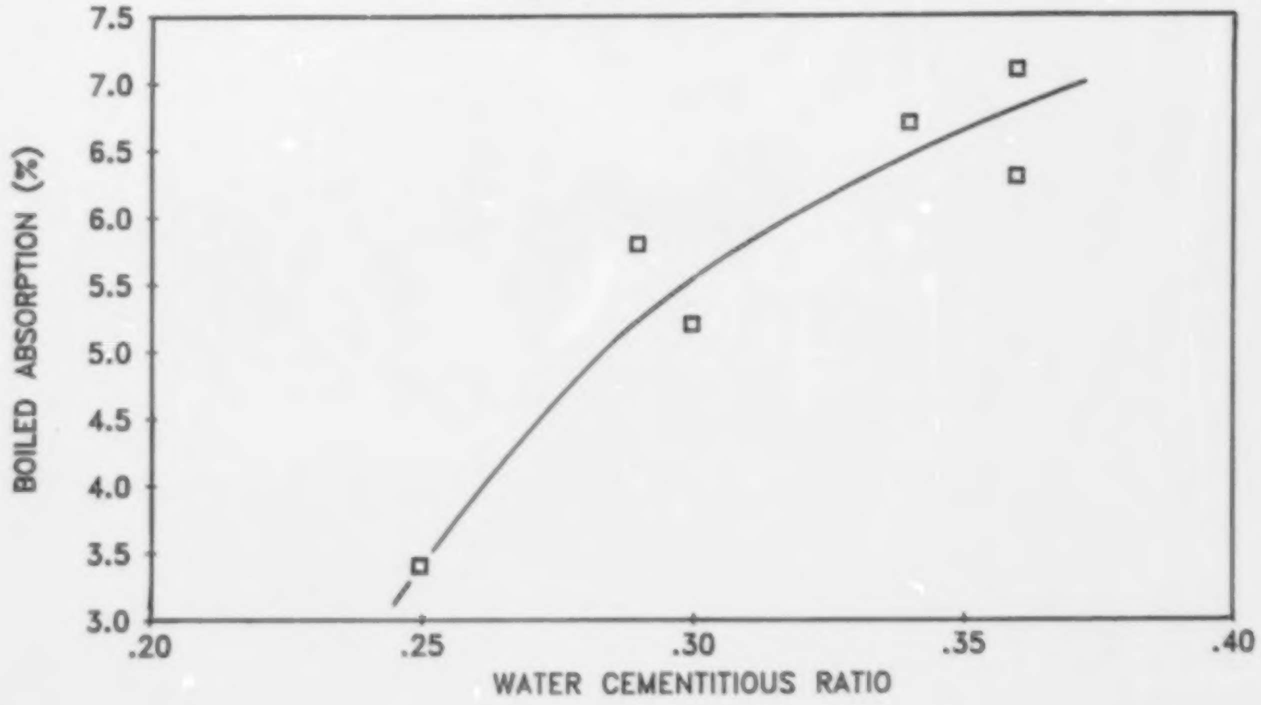
REFERENCES

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

FIGURE 3

SCALE
DATE
MADE P.
CHKD
JOB No.
FIGURE

RELATIONSHIP BETWEEN BOILED ABSORPTION
AND
WATER/CEMENTITIOUS RATIO



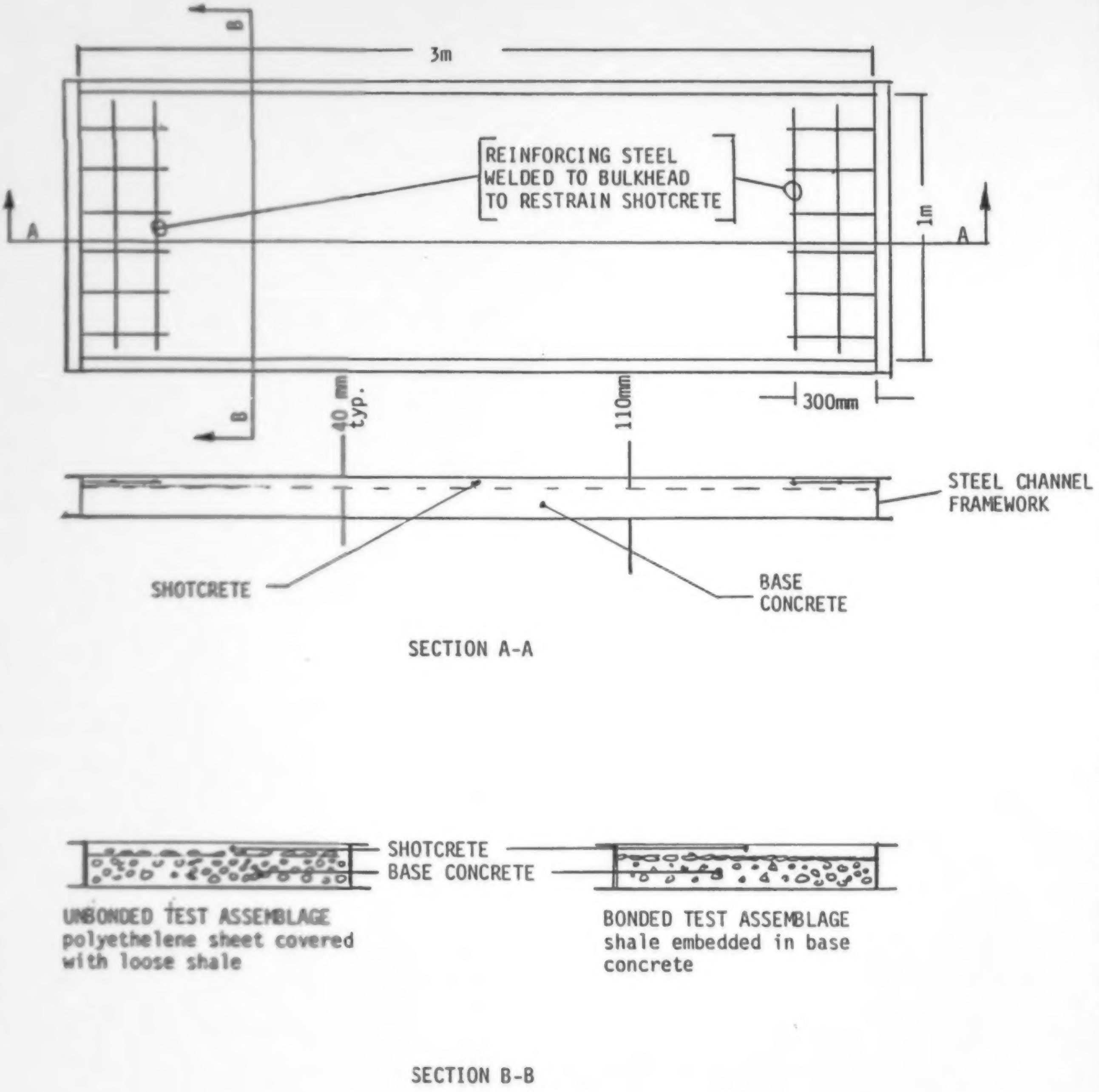
REVISIONS

REFERENCES

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

FIGURE 4

SCALE
DATE DEC 20/89
MADE P.Mc
CHKD
JOB No VA 01584
FIGURE



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

Figure 5
DETAILS OF RESTRAINED SHRINKAGE TEST

Scale	Date	Drawn By
N/A	88.06.20	N. McA

APPENDIX B

PHASE II INVESTIGATIONS - HARDY BBT LTD.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B1
SIEVE ANALYSIS REPORT

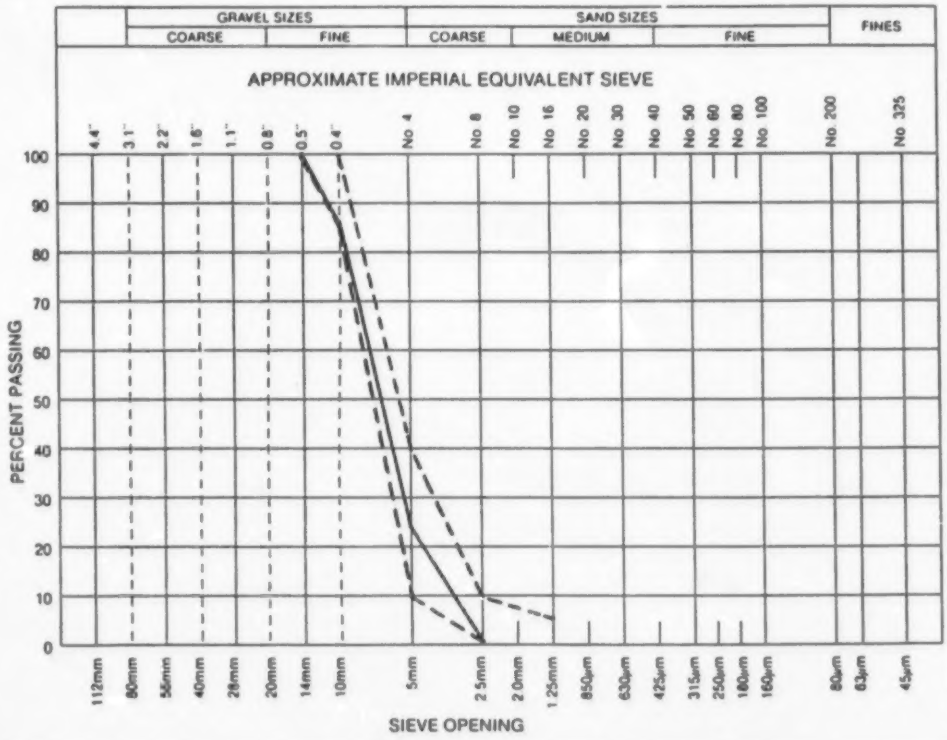
TO:
SCIENCE & PROFESSIONAL SERVICES DIR.
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. W. John Humphries

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE 10 mm Aggregate
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	86.6
No. 4	24.4
No. 8	0.4

SAMPLE DESCRIPTION: 10 mm shotcrete aggregate from Target Products Ltd., Burnaby, B.C.

COMMENTS 10 mm Shotcrete Aggregate Plotted vs CAN3-A23.1-M77, Table 3; Group I
10 - 2.5 mm Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B2

SIEVE ANALYSIS REPORT

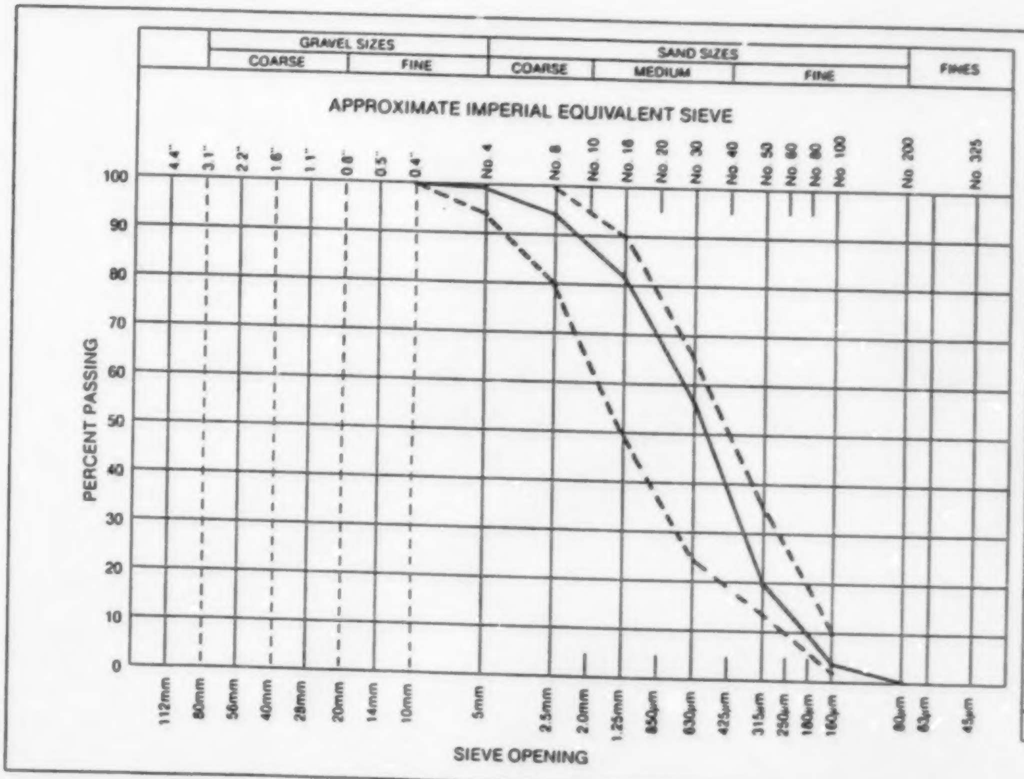
TO:
SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place du Portage - Phase III,
11 Laurier Street,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. W. John Humphries

OFFICE: VANCOUVER
PROJECT NO.: VA-01584
CLIENT:
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE Sand
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
3/8"	100.0
No. 4	99.1
No. 8	93.8
No. 16	89.1
No. 30	56.7
No. 50	19.6
No.100	3.4
No.200	0.5

SAMPLE DESCRIPTION: Shotcrete sand from Target Products Ltd., Burnaby, B.C.

COMMENTS Sand Gradation Plotted vs. CAN3-A23.1-M77, Table 1 Fine Aggregate Gradation Envelope

Hardy BBT Limited
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written request.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B3

SIEVE ANALYSIS REPORT

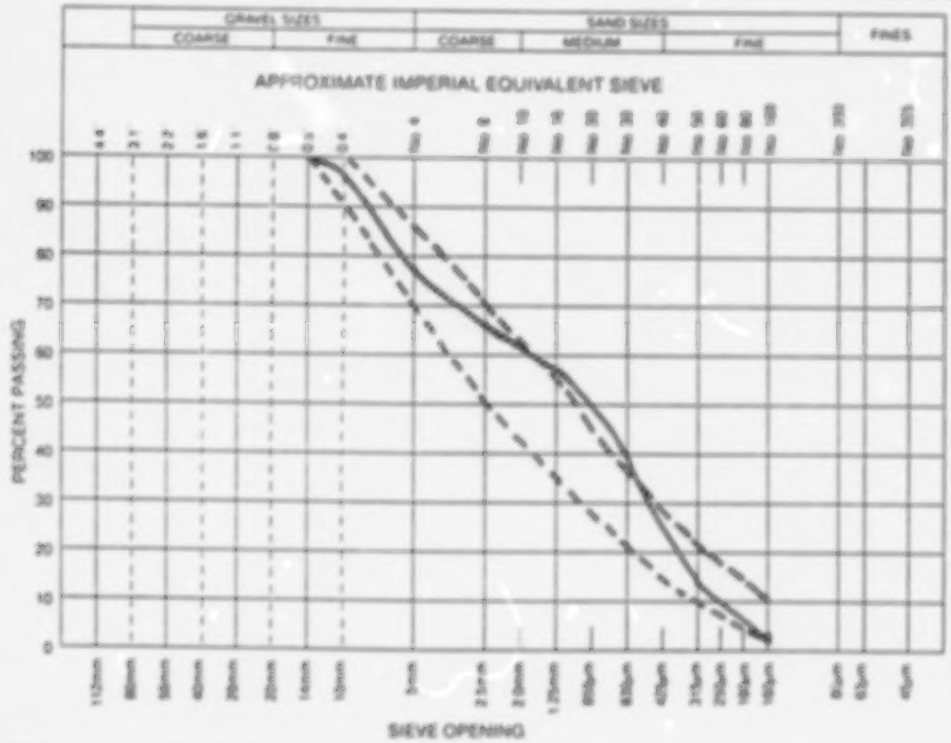
TO SCIENCE AND PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

OFFICE VANCOUVER
PROJECT NO VA-01584
CLIENT
COPIES TO

PROJECT SHOTCRETE STUDY - HALIFAX AIRPORT

SAMPLE I.D. Target
TYPE OF SAMPLE Combined
SAMPLED BY D. Hatch
DATE SAMPLED
DATE RECEIVED
DATE TESTED
SOURCE



SIEVE SIZE	PERCENT PASSING
1/2"	100.0
3/8"	96.0
No. 4	76.7
No. 8	65.8
No. 16	57.5
No. 30	39.7
No. 50	13.7
No. 100	2.4
No. 200	0.4

SAMPLE DESCRIPTION Combined blend of 70:30 :: Sand:10 mm Coarse Aggregate by Mass

COMMENTS Combined Blend Shown V. ACI 506R-85, Table 2.2.1, Gradation No. 2 Envelope

Hardy BBT Limit
Per D. R. Morgan

Reporting of these test results constitutes a testing service only. Engineering interpretation or evaluation of the test results is provided only on written requ

HR T 74-87/86

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #84

TO:

SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX U

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m³)	VOLUME (m³)
Cement (Type 10)	161	3150	0.0512
Fly Ash (Type F)	269	2640	0.1019
Coarse Aggregate (SSD) 10 mm x 5 mm	541	2707	0.1997
Sand (SSD)	1267	2652	0.4777
Water	108	1000	0.1080
Water Reducing Admixture DURASAR (ml/100 kg)	2200	1000	0.0095
Air Content (as shot)	5.2		0.0520
TOTALS:	2348		1.0000

Sand Content = Ps = 70%

Approximate W/(C + FA) RATIO = 0.25

Theoretical Plastic Density = 2348 kg/m³

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #85

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX V

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	157	3150	0.0498
Fly Ash (Type F)	261	2640	0.0987
Coarse Aggregate (SSD) 10 mm x 5 mm	520	2707	0.1920
Sand (SSD)	1220	2652	0.4600
Fibre (Polypropylene)	3.1	920	0.0034
Water	152	1000	0.1519
Water Reducing Admixture DURASAR (ml/100 kg)	1250	1000	0.0052
Air Content (as shot)	3.9		0.0390
TOTALS:	2318		1.0000

Sand Content = Ps = 70.1%

Approximate W/(C + FA) RATIO = 0.36

Theoretical Plastic Density = 2318 kg/m^3

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B6

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX W

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	158	3150	0.0502
Fly Ash (Type F)	264	2640	0.1000
Coarse Aggregate (SSD) 10 mm x 5 mm	520	2707	0.1921
Sand (SSD)	1223	2652	0.4612
Fibre (Polypropylene)	6.4	920	0.0069
Water	149	1000	0.1490
Water Reducing Admixture DURASAR (ml/100 kg)	995	1000	0.0042
Air Content (as shot)	3.6		0.0360
TOTALS:	2325		1.0001

Sand Content = Ps = 70.2%

Approximate W/(C + FA) RATIO = 0.35

Theoretical Plastic Density = 2325 kg/m^3

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B7

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

ATTENTION: Mr. John Humphries

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX X
SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	172	3150	0.0546
Fly Ash (Type F)	312	2640	0.1181
Coarse Aggregate (SSD) 10 mm x 5 mm	507	2707	0.1872
Sand (SSD)	1198	2652	0.4518
Water	147	1000	0.1470
Water Reducing Admixture DURASAR (ml/100 kg)	893	1000	0.0043
Air Content (as shot)	3.7		0.0370
TOTALS:	2340		0.9999

Sand Content = Ps = 70.3%

Approximate W/(C + FA) RATIO = 0.30

Theoretical Plastic Density = 2340 kg/m^3

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B8

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX Y

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	174	3150	0.0551
Fly Ash (Type F)	313	2640	0.1187
Coarse Aggregate (SSD) 10 mm x 5 mm	500	2707	0.1847
Sand (SSD)	1185	2652	0.4466
Fibre (Polypropylene)	3.3	920	0.0035
Water	142	1000	0.1420
Water Reducing Admixture DURASAR (ml/100 kg)	901	1000	0.0044
Air Content (as shot)	4.5		0.0450
TOTALS:	2322		1.0000

Sand Content = Ps = 70.3%

Approximate W/(C + FA) RATIO = 0.29

Theoretical Plastic Density = 2322 kg/m^3

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #B9

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch, 11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 89-12-19
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT - MIX Z

SUBJECT: AS-BATCHED SHOTCRETE MIXTURE PROPORTIONS FOR PHASE II FIELD SHOTCRETE STUDY

MATERIAL	MASS (kg)	BULK DENSITY (kg/m^3)	VOLUME (m^3)
Cement (Type 10)	168	3150	0.0533
Fly Ash (Type F)	303	2640	0.1148
Coarse Aggregate (SSD) 10 mm x 5 mm	489	2707	0.1807
Sand (SSD)	1159	2652	0.4368
Fibre (Polypropylene)	6.5	920	0.0071
Water	158	1000	0.1580
Water Reducing Admixture DURASAR (ml/100 kg)	916	1000	0.0043
Air Content (as shot)	4.5		0.0450
TOTALS:	2288		1.0000

Sand Content = Ps = 70.3%

Approximate W/(C + FA) RATIO = 0.34

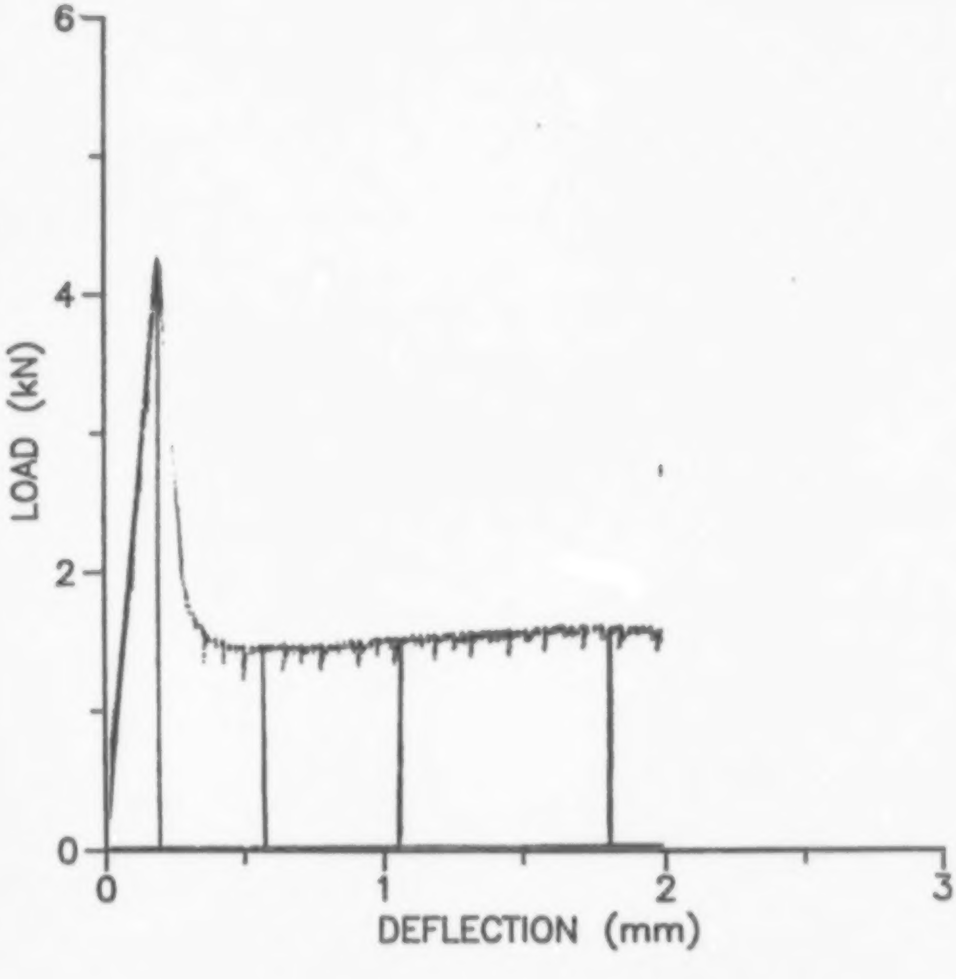
Theoretical Plastic Density = 2288 kg/m^3

APPENDIX C

PHASE II INVESTIGATIONS - HARDY BBT LTD.

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: V-B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

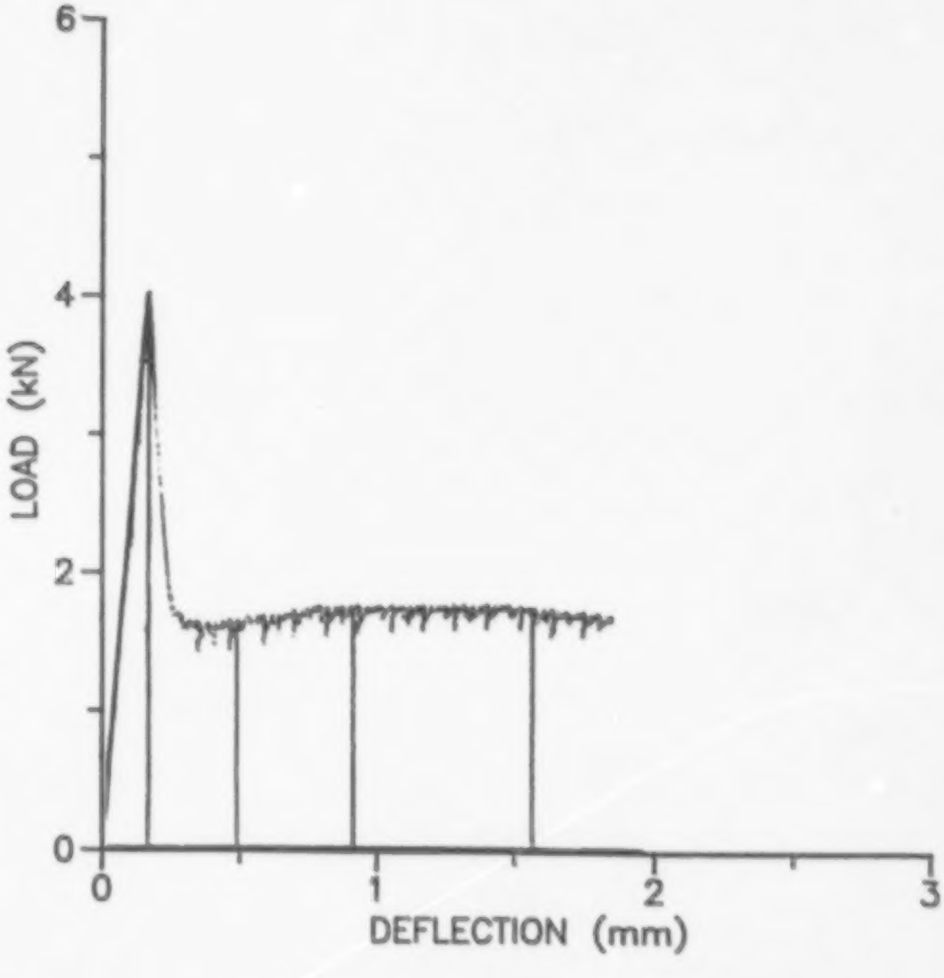
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 94-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: V-C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m³



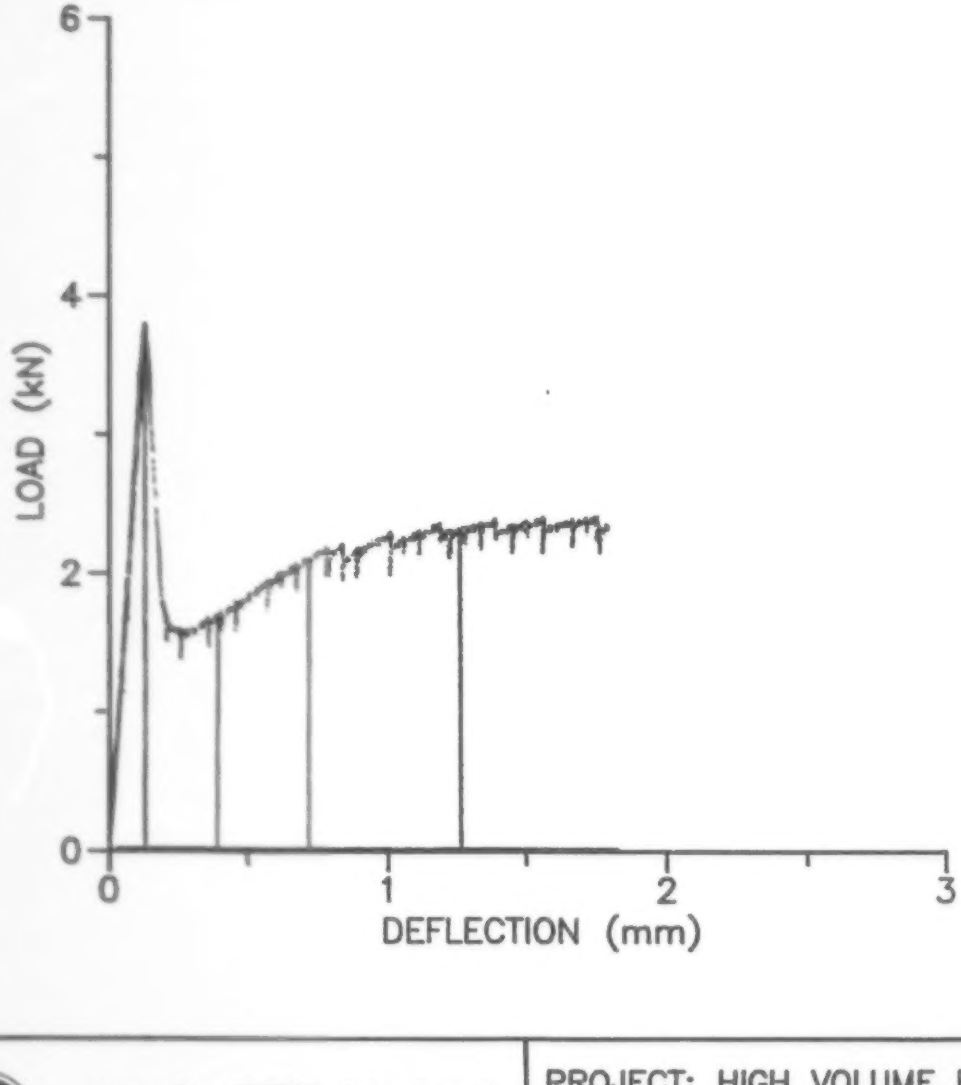
Hardy BBT Limited CONSULTING ENGINEERING & PROFESSIONAL SERVICES	PROJECT: HIGH VOLUME FLY ASH PFRS CLIENT: SUPPLY AND SERVICES CANADA JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 84-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: W-A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



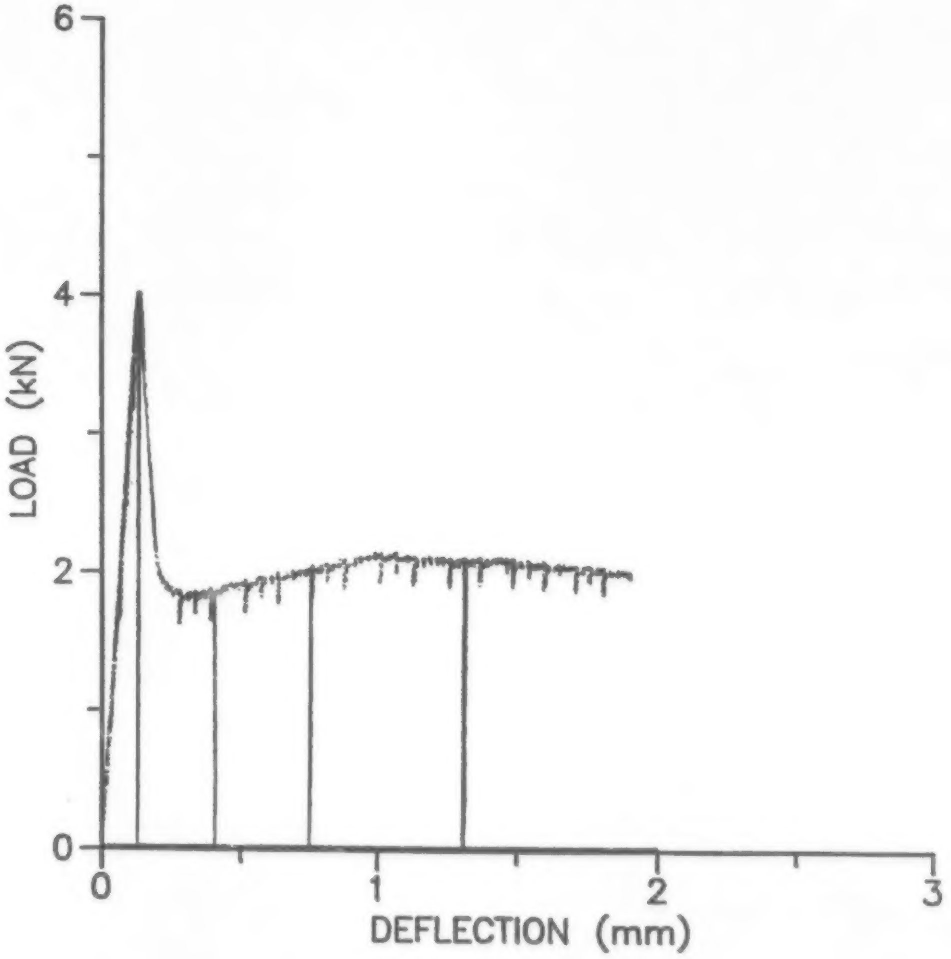
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: W-B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

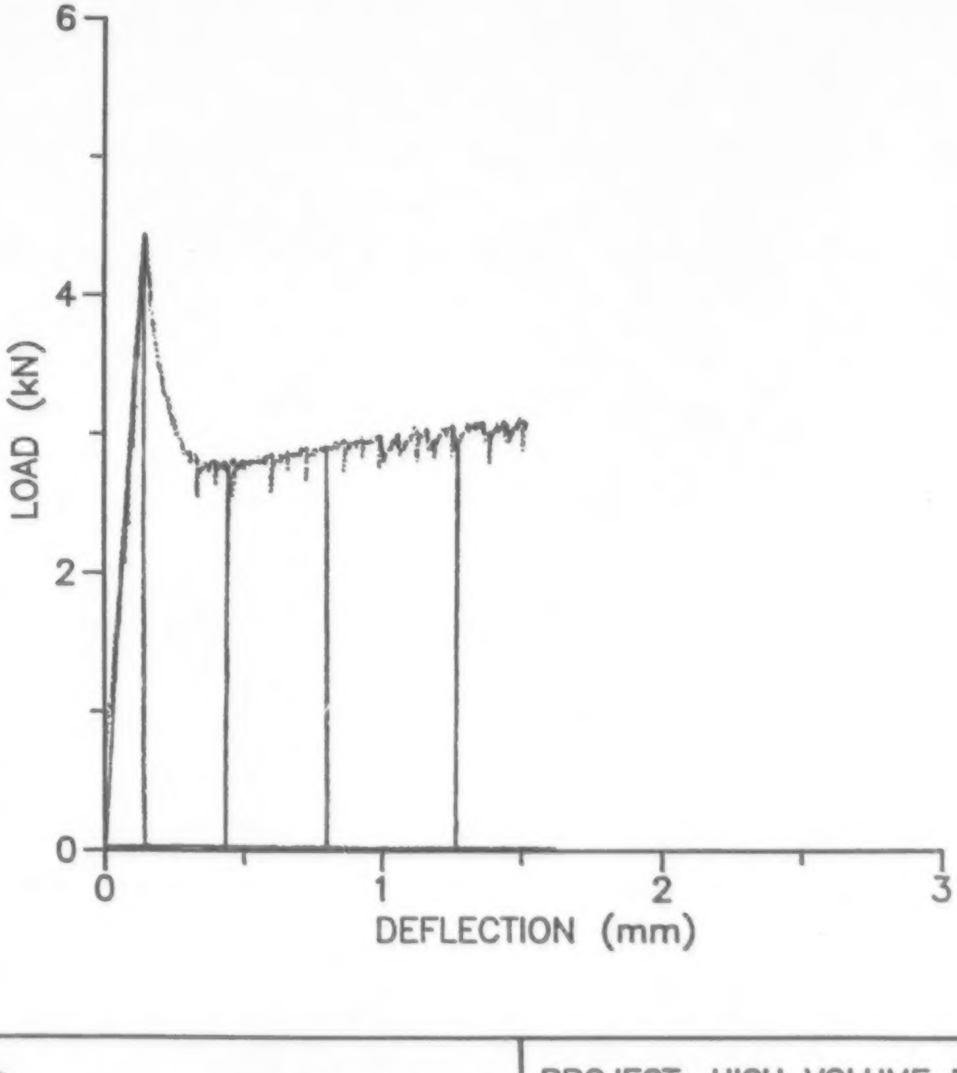
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 54-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: W-C   AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.4 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

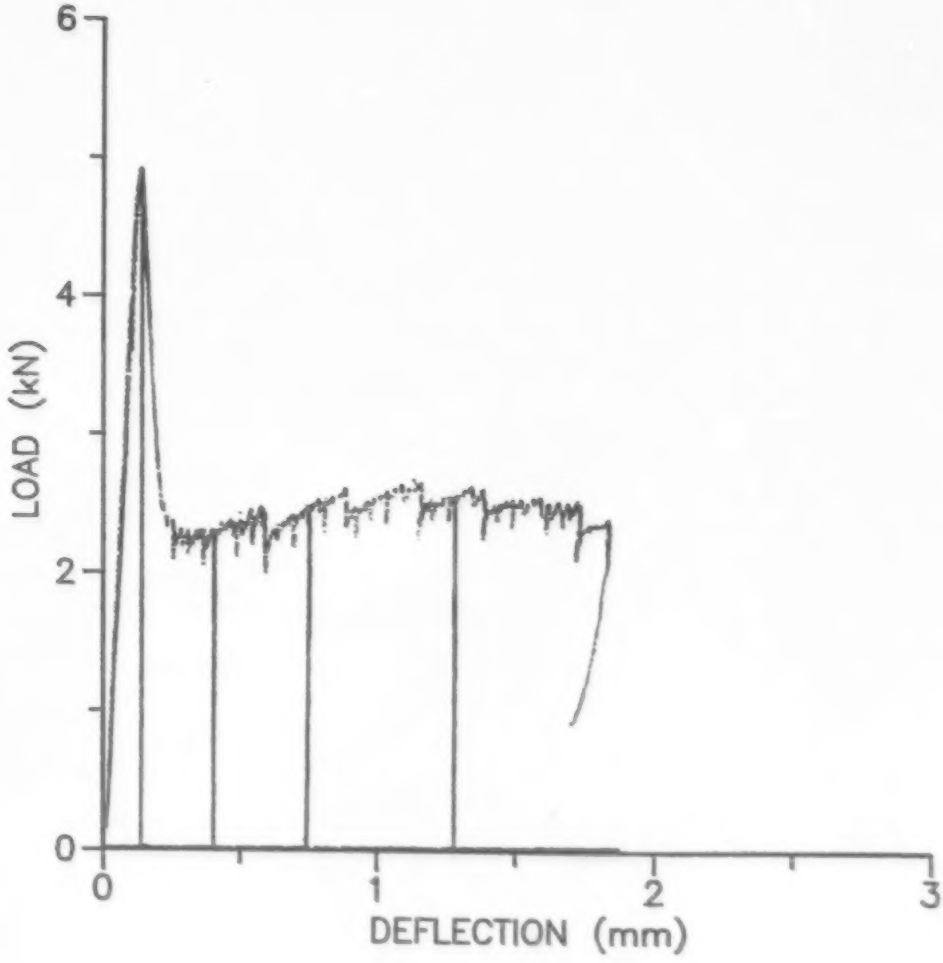
SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 54-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Y–A   AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.1 kg/m³

X



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

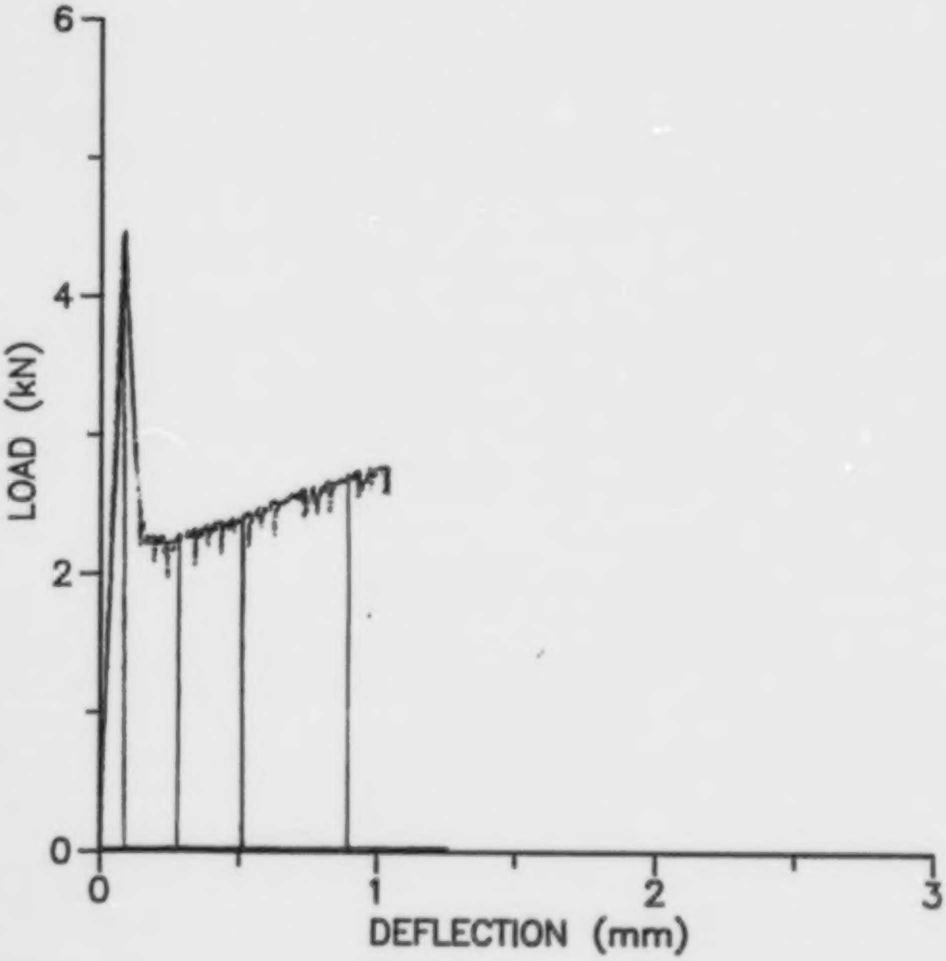
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S. | DATE 89–12–12 | MADE D.H. | CHKD. ______ | JOB No. ______ | FIGURE ______

HBLT 54-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Y-B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.1 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

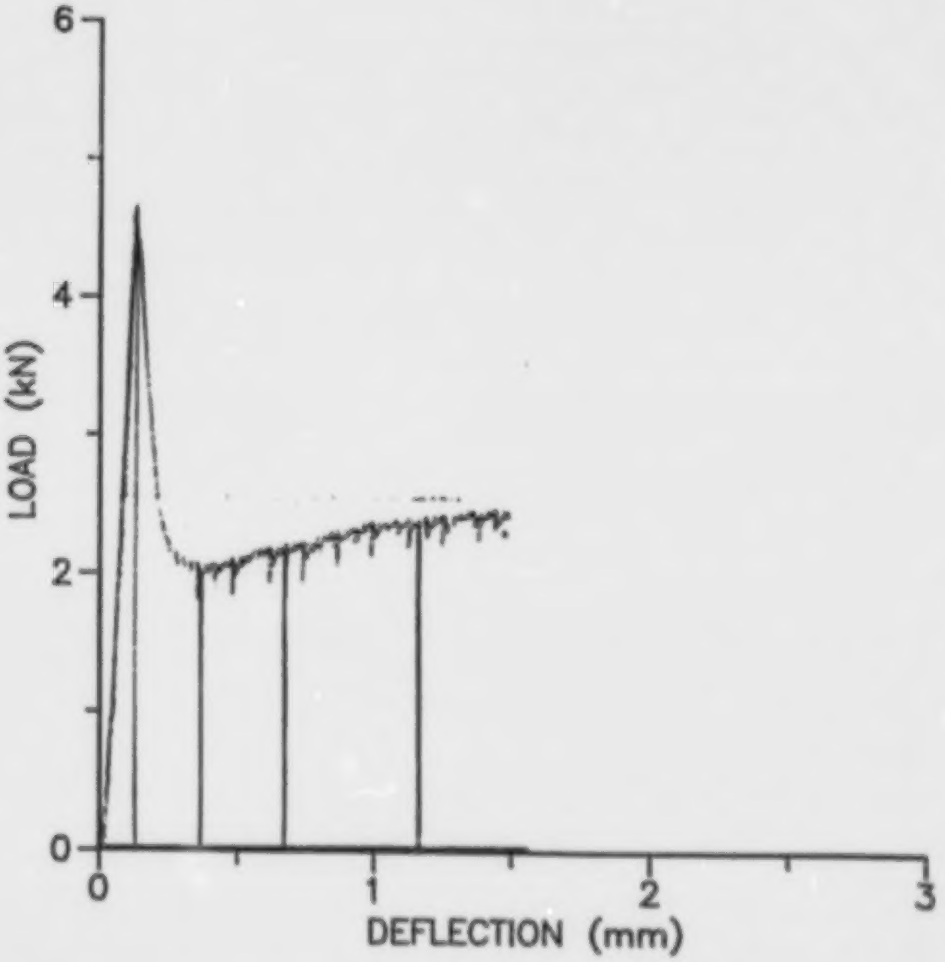
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 04-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Y-C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.1 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

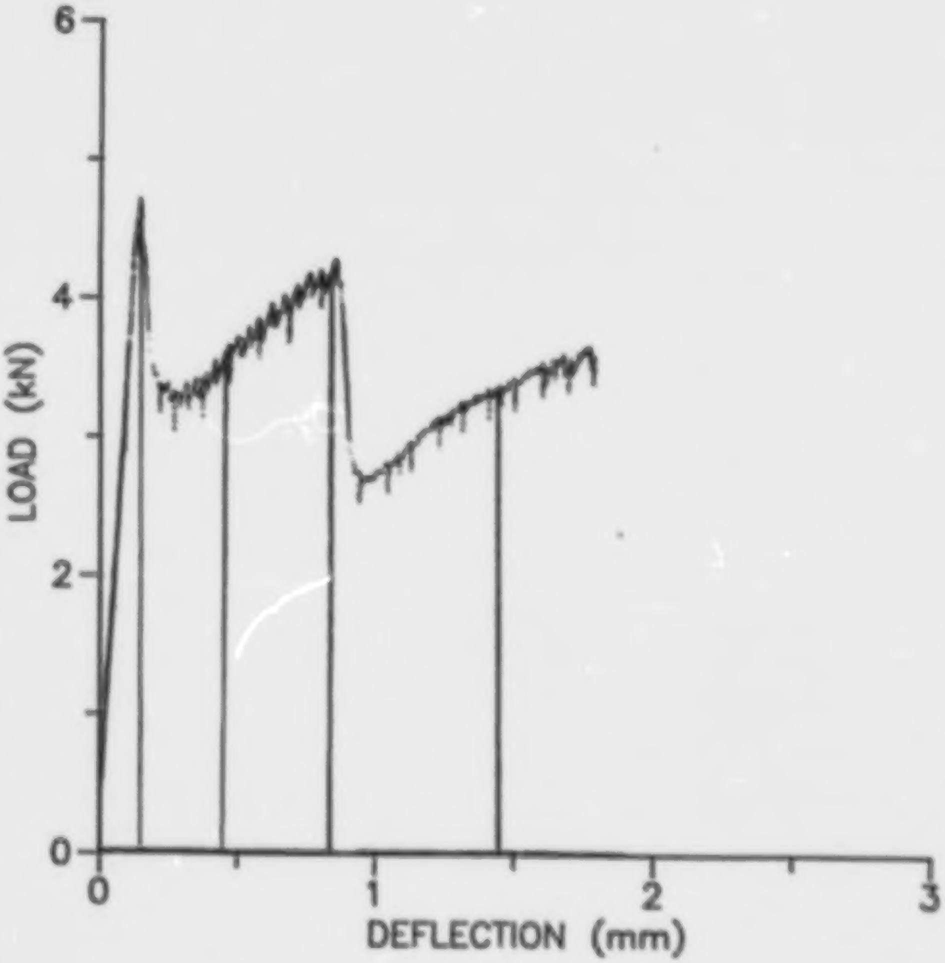
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 94-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Z-A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.5 kg/m³



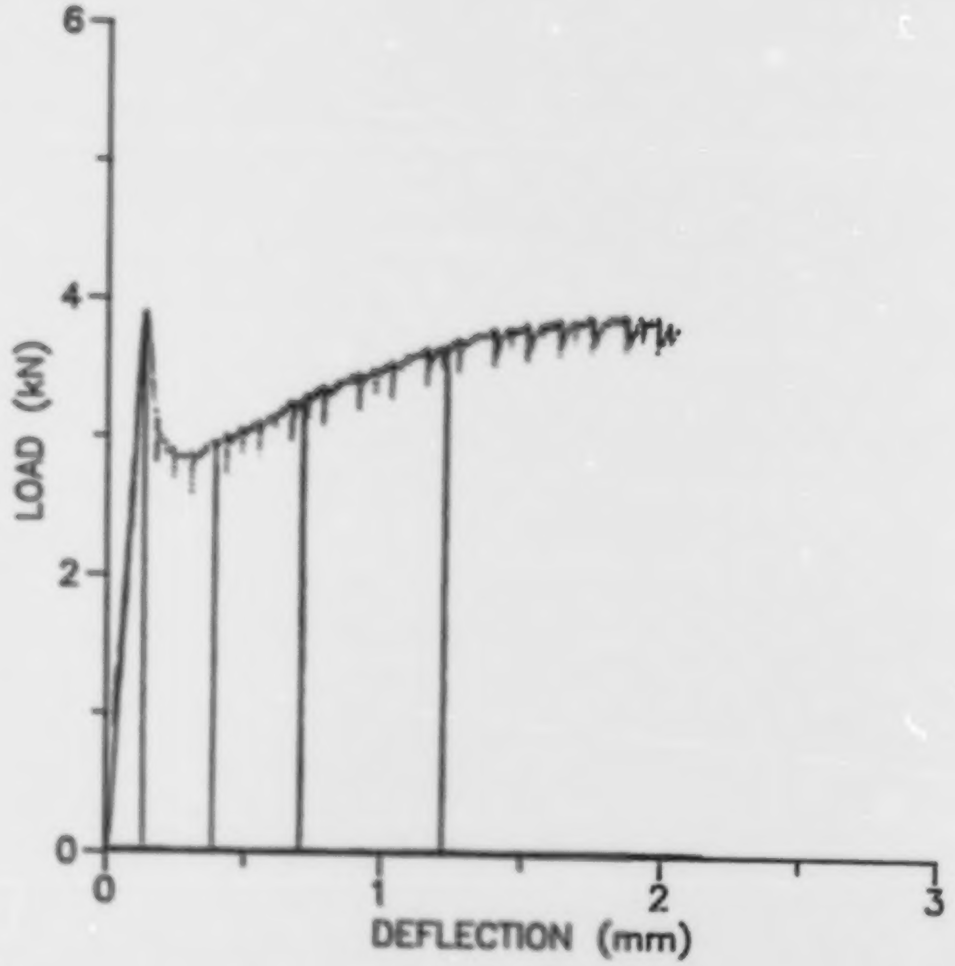
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Z-B AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.5 kg/m³



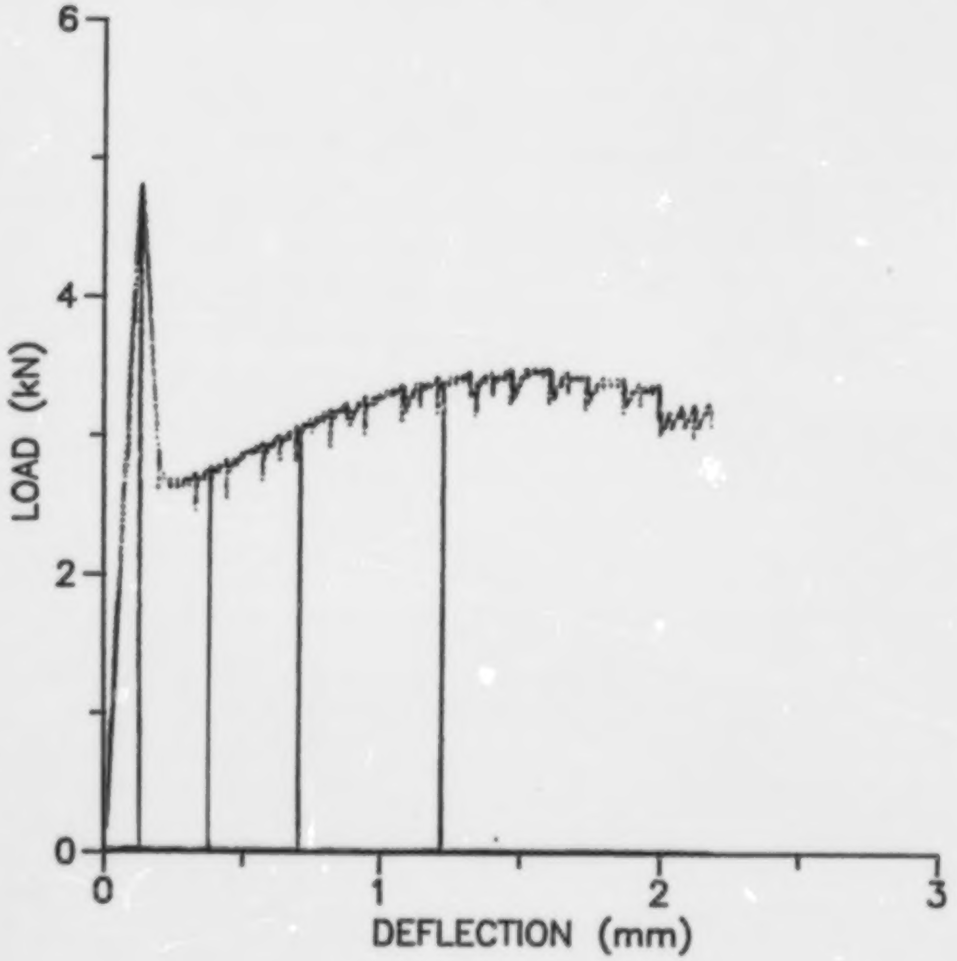
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE TO ASTM C1018-85

SPECIMEN NO.: Z-C AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 6.5 kg/m³



Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

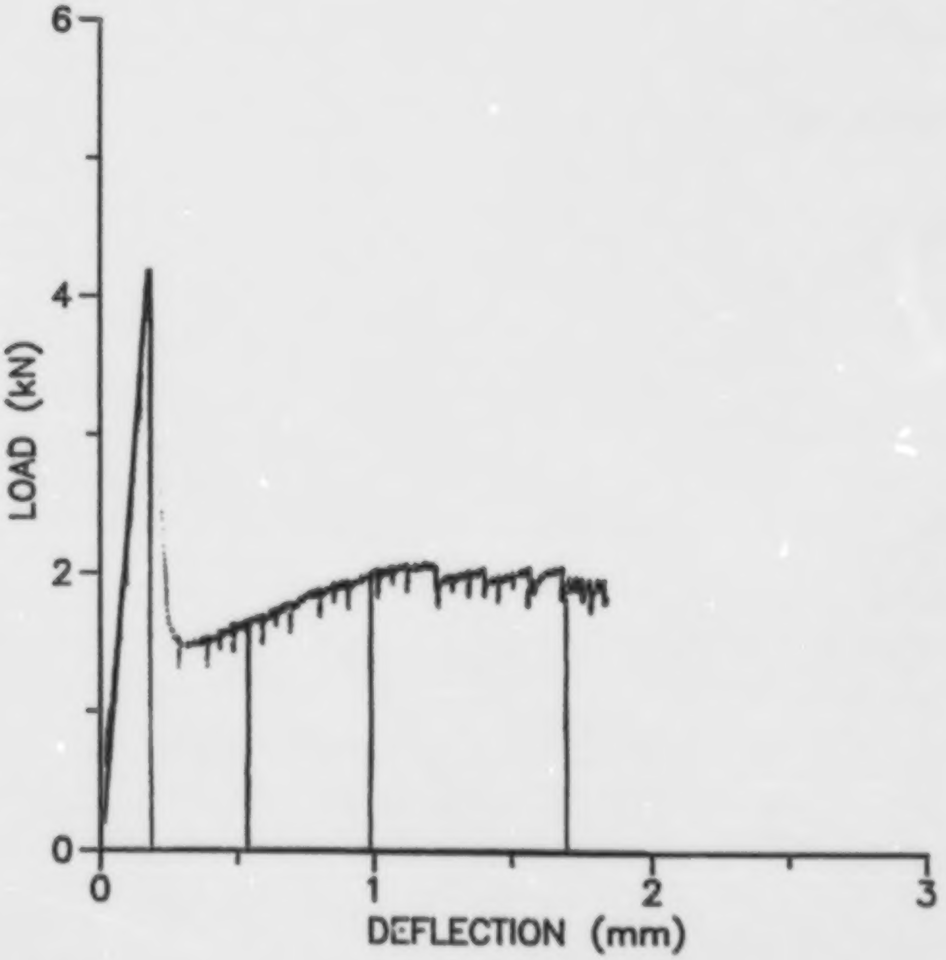
PROJECT: HIGH VOLUME FLY ASH PFRS
CLIENT: SUPPLY AND SERVICES CANADA
JOB NO.: VA1584

SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 54-87/11

FLEXURAL STRENGTH OF FIBRE REINFORCED SHOTCRETE
TO ASTM C1018-85

SPECIMEN NO.: V-A AGE OF TEST: 28 DAYS
SPECIMEN SIZE: 75 x 75 x 355 mm
FIBRE TYPE: 38 mm FORTA CR POLYPROPYLENE FIBRE
FIBRE DOSAGE: 3.3 kg/m³



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SCALE N.T.S.	DATE 89-12-12	MADE D.H.	CHKD.	JOB No.	FIGURE

HBLT 04-87/11

APPENDIX D

PHASE II INVESTIGATIONS - HARDY BBT LTD.

3 | CONCRETE REINFORCEMENT
Crack-Control Reinforcement

FORTA Corporation
November 1987
(Supersedes November 1985)

FORTA™

SPEC-DATA®

This Spec-Data sheet conforms to editorial style prescribed by The Construction Specifications Institute. The manufacturer is responsible for technical accuracy.

1. PRODUCT NAME

FORTA™ CR® (Concrete Reinforcement)

2. MANUFACTURER

FORTA Corporation
100 Forta Drive
Grove City, PA 16127-9990
Phone: 1-800-245-0306
1-800-222-8907 in PA
1-412-458-5221
Telex: 812 535 FORTA GRCT
FAX: 412-458-8331

3. PRODUCT DESCRIPTION

General Description: FORTA CR is a twisted bundle, CFP (collated fibrillated polypropylene) fibrous reinforcement.

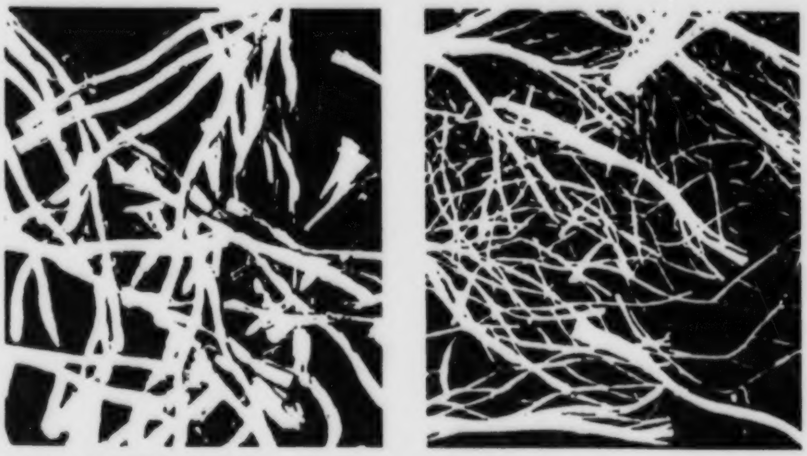
Basic Use: FORTA CR is used as a secondary, crack-controlling reinforcement for concrete. FORTA CR may be used to replace welded wire fabric (wire mesh) in any application where the mesh is used as temperature/shrinkage reinforcement.

General Applications: Major application areas for FORTA CR include cast-in-place concrete, air-placed concrete, and precast concrete elements.

Cast-in-place applications include industrial floors, parking lots, pavements, and residential concrete. Air-placed applications include water reservoir liners, irrigation ditches, tunnel and culvert liners, man-made rock and waterscapes, and bridge deck overlays. Precast concrete uses include wall panels, septic tanks, vaults, and various ornamental products.

Benefits: From an economic standpoint, the use of FORTA CR eliminates the costs associated with the handling and placement of wire mesh in both site-cast and precast applications. From a technical value-added standpoint, the uniform, three-dimensional fibrous distribution allows FORTA CR to control cracking better than the single-plane layer of wire mesh. The single purpose of wire mesh, when used as secondary/temperature reinforcement, is to hold the concrete together *after* it cracks. Due to the uniform fibrous reinforcement coverage, FORTA CR not only controls the cracking process more effectively, but also contributes to a number of additional concrete properties.

The additional benefits of FORTA CR include the reduction of plastic and hardened concrete shrinkage and permeability, and improved impact resistance, ductility, fatigue strength, and toughness. Also, test data per ASTM C-944 shows that FORTA CR significantly reduces floor surface abrasion as compared to plain concrete.



Twisted FORTA™ CR® bundles spring open during mixing.

Limitations: FORTA CR is considered as a secondary reinforcement. FORTA CR will not replace primary reinforcement intended to support structural loads. FORTA Corporation's engineering group will assist in evaluating any potential application.

Dosage Rates: FORTA CR is packaged in 1.6 pound bags, which is the recommended quantity for one cubic yard of concrete. For metric applications, FORTA CR is packaged in one kilogram bags. These dosage rates have been determined by engineering testing and by extensive use of FORTA CR in conventional applications where wire mesh is being replaced as a secondary reinforcement. Higher volumes per cubic yard have shown improvement to the toughness index of the fibrous concrete—consult FORTA Corporation for additional details.

Four twisted fibrous bundle lengths are manufactured by FORTA Corporation. The fibrous bundle length is matched with the maximum top-size of the coarse aggregate used in the mix. The effective bond length of a fibrous reinforcement is approximately 50% of the actual bundle length. Therefore, resistance to pull out/debonding and the utilization of the material's ultimate tensile strength are realized when the longest bundle length that can be properly mixed and uniformly distributed in a given mix is specified. (See bundle length per aggregate size chart in Table 1.)

Table 1

PRODUCT TYPE	BUNDLE LENGTH	AGGREGATE TOP-SIZE	AASHTO SIZE
A-5	¾"	¼"–	10–
A-10	1½"	½"	8–
D-15	2¼"	¾"	67–
D-24	2½"	1"+	57+

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Approvals—Specifications: For precast septic tank and water distribution box products, FORTA Corporation has obtained approvals from numerous state and local agencies for use as secondary/handling reinforcement in lieu of wire mesh. (Contact FORTA Corporation for specific approvals.) For flatwork, both I.C.B.O. Evaluation Report #4151 (in compliance with the 1985 Uniform Building Code) and FORTA's U.S.–GSA Contract #G.S.-00F-79582 (for federal government purchase) are available to the architect and engineer upon request.

FORTA Corporation suggests that current consensus standards and practices be followed in the design, placing, and finishing of concrete.

4. TECHNICAL DATA

Chemical: FORTA CR consists of a virgin homo-polymer polypropylene in combination with other chemicals and additives defined by FORTA Corporation to meet precise engineering standards. FORTA CR is chemically inert and non-hazardous in the form supplied. FORTA CR will not react with any components found within the concrete, such as chemical admixtures, alkalis, or calcium chloride, and will not rot or corrode. Also, FORTA CR will not react with the components used to cure and seal the concrete, nor with the vast majority of materials that may come in contact with the concrete including organic acids. FORTA CR also contains a color additive to facilitate camouflaging with cured concrete and to enhance the surface U.V. stability. Both the FORTA Technical Report: Chemical Resistance of FORTA CR Fibrous Reinforcement and the O.S.H.A. Material Safety Data Sheet #20 (in voluntary, non-required compliance with O.S.H.A. Hazard Communication Standard, 29 CFR 1910.1200) are available upon request.

Physical Properties: Due to the chemically inert nature of FORTA CR and subsequent need for mechanical fibrous bonding with the cement matrix, FORTA Corporation utilizes a manufacturing process that is engineered solely to enhance the bonding of the FORTA in the concrete matrix. FORTA CR's fibrillation pattern (screen formation) is comprised of coarse main fibrils and lesser diameter connecting fibrils. This method reduces the risk of fibrous debonding and pull-out from the concrete matrix that would occur with small diameter unidimensional screen or monofilament fiber products.

Additional physical characteristic data include:

Specific Gravity	0.91
Density	56 lbs./cu. ft.
Modulus of Elasticity	0.70×10^6 p.s.i.
Tensile Strength	70,000 p.s.i. (Minimum)
Lengths	¾", 1½", 2¼", 2½"
Volume at 1.6 lb./cu. yd.	0.1%
Elongation at Break	8%
Per ASTM E84-80	
Flame Spread Index	1.6
Fuel Contribution	0.0
Smoke Density	0.0

5. INSTALLATION

Addition/Mixing Procedures: FORTA CR is very easy to add—one pre-weighed bag per cubic yard of concrete. It may be added with the coarse and fine aggregates at the batch plant, or directly to the mixer on the job site. When added at the batch plant with the other ingredients, no additional site mixing time is required. If added to the already mixed concrete, approximately three to five minutes of mixing are required. If a superplasticizer is used with the FORTA CR at 1.6 lb. per cubic yard, add and mix the FORTA CR first. We suggest that when adding FORTA CR to a ready mix truck, the concrete should be brought to the back of the mixer, especially if the drum contains less than 50% of capacity (i.e. for 4 cubic yards in a 10 yard capacity drum, back the concrete up to top of discharge and empty FORTA CR on top of concrete before mixing). Due to the twisted bundle configuration, it is not necessary to sprinkle or "ribbon" the FORTA CR into the mixing system.

The FORTA CR reinforced concrete can be mixed and pumped or air-placed with no special equipment necessary.

If a conventional slump test is required, perform the test in accordance with ASTM C143 prior to adding the FORTA CR. Using this conventional slump test will indicate a lower test value for fibrous concrete than for plain concrete with the same w/c ratio. If preferred, ASTM C995 can be used to measure the consistency and actual flowability of the fibrous reinforced concrete.

NOTE: Fibrous reinforced specimens should be externally vibrated and not internally rodded per ACI Committee 544 recommendations.

6. AVAILABILITY AND COST

Availability: FORTA CR can be purchased domestically and internationally. In the United States, orders are shipped from the factory within 24 hours by UPS, commercial carrier, or air freight.

Cost: The in-place cost (4" thick slab) is approximately $0.10 per square foot. Exact delivered costs may be obtained from a local FORTA dealer or from FORTA Corporation.

7. WARRANTY

FORTA CR is warranted to be free of defects and to meet all quality control standards set by the manufacturer. FORTA Corporation has no control over the design, production, placement, or testing of the concrete products in which FORTA CR is incorporated, therefore FORTA Corporation assumes no responsibility for the end products.

8. MAINTENANCE

Not applicable.

9. TECHNICAL SERVICES

Complete technical services and assistance are available by contacting the FORTA Corporation engineering group, or the local FORTA technical representative.

10. FILING SYSTEMS

SPEC-DATA® II
Sweet's Engineering Catalogue #03200/FOR
I.C.B.O. Evaluation, Report #4151

FORTA™ CR® and ❋® are trademarks of FORTA Corporation.

HANDY

745, Ste-Rose St., La Prairie, Qué. J5R 1Z2

DURASAR
SUPER PLASTICIZER FOR CONCRETE

- DURASAR is a cost effective non-alkaline, extremely low sulfate and chloride free Superplasticizer. It is an efficient fluidifier and a high range water reducer agent (Superplasticizer) thereby contributing excellent rheological properties to concrete.
- DURASAR improves the flow properties of the mixture by breaking up cement agglomerates to produce lower viscosities.
- DURASAR Superplasticizer concrete does not show a high rate of slump loss.
- DURASAR will increase the mechanical properties of concrete; i.e. compressive and flexural strengths and modulus of elasticity.
- DURASAR's dispersion effect on cement particles improves the efficiency of hydration.

DURASAR can be used to produce:

- Flowing self-levelling concrete
- High early strength concrete
- Low water-to-cement ratio
- Very high strength concrete (100 MPa - 15,000 psi)
- Reduced water requirements by 20%-30%

- DURASAR can be used for:

  Pumping concrete
  Underwater applications
  Gunite applications
  Special shaped concrete slabs
  Precasting
  Architectural concrete

- DURASAR should be used for production of:

  Commercial concrete
  Fly ash concrete
  Blast furnace slag cement concrete
  Lightweight concrete
  Numerous cementitious systems

DURASAR meets the requirements of the Canadian Standards Specifications CAN3-A266.6-M85 Superplasticizing Admixtures for Concrete.

DOSAGE:

DURASAR is normally used at a rate of 0.5-2.0 litres per 100 kg. (9.0-20.0 fluid oz. per 100 lb.) of cement. Other dosages may be required depending on specific conditions.

TYPICAL PROPERTIES:

Chemical classification:	Naphthalene sulfonate calcium salt
Appearance:	Clear, brown liquid
Active content:	38.0% ± 1.0%
Sulfate percentage:	0.20% ± 0.05%
pH 10% solution	7.5 ± 0.5
Specific gravity at 23° C.	1.19 ± 0.02
Freezing point	-4.0° C. (25° F)
Chlorides	Nil
Ionic nature	Anionic
Solubility, aqueous	Clear, instantly in hard, or soft water

WORKABILITY:

DURASAR fluidified concrete remains workable for approximately one hour at 20° C. (68° F). The duration of workability depends not only on temperature, but also on the type and brand of cement, the nature of the aggregates and the method of transportation. When DURASAR is used at normal suitable dosage levels, it will not significantly affect the concrete's heat of hydration.

PACKAGING, STORAGE AND HANDLING:

DURASAR is supplied in 260 Kg. drums or in bulk. It will freeze at -4.0° C. (25° F.). If frozen, warm to 22° C. (72° F.) mix well. Its working properties will not be affected if frozen. Storage of DURASAR at room temperature is recommended.

SAFETY AND HANDLING PRECAUTIONS:

DURASAR is a non-alkaline material. Direct contact may cause irritation of eyes. Prolonged contact may cause skin irritation. May be harmful if swallowed. Do not get in eyes. Avoid prolonged skin contact. Wash thoroughly after handling. Do not take internally.

WARRANTY STATEMENT:

The information given here is based on our best knowledge and we believe it to be true and accurate. We assume no responsibility for the use of these statements, recommendations or suggestions, nor do we intend them as a recommendation for any use which would infringe any patent or copyright.

MANUFACTURED BY:- HANDY CHEMICALS LIMITED
745 Ste. Rose Street
La Prairie, Quebec
CANADA J5R 1Z2

Telex: 05-24489 Tel.: (514) 659-9693

APPENDIX E

PHASE II INVESTIGATIONS - HARDY BBT LTD.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

VA-01584

February 16, 1990

Science and Professional Services Directorate,
Science Branch,
11C1 Place du Portage, Phase III,
11 Laurier,
HULL, QUEBEC
K1A 0S5

ATTENTION: Mr. John Humphries

Dear Sirs:

Re: Phase II - Halifax Airport
Cement/Fly Ash Sealant
Final Report

Hardy BBT Limited have now completed the final work outstanding on this contract; i.e. freeze/thaw durability studies and restrained drying shrinkage cracking studies. The results of these studies (and the overall test program) were presented verbally at a debriefing session with CANMET and Transport Canada, in Ottawa, on February 5, 1990. The results of the freeze/thaw durability tests to ASTM C666, Procedure A are given in the appended Technical Report. It can be seen that all the shotcrete mixtures tested displayed good resistance to deterioration from freezing and thawing at the conclusion of 300 cycles of testing. Average durability factors ranged from 91.6 to 98.5 percent. The specimens all displayed slight scaling, as is evident from the average weight losses on the prisms, which varied from 1.4 to 3.0 percent. These observations are consistent with the results of freeze/thaw durability testing reported by CANMET in the complementary studies conducted by them.

4052 GRAVELEY STREET, BURNABY, BRITISH COLUMBIA V5C 3T6 TELEPHONE (604) 294-3811 FAX (604) 294-4664
GEOTECHNICAL AND MATERIALS ENGINEERING — ENVIRONMENTAL, MATERIALS AND CHEMICAL SCIENCES
BONNYVILLE CALGARY EDMONTON FORT McMURRAY KAMLOOPS LETHBRIDGE LLOYDMINSTER MEDICINE HAT
NANAIMO PEACE RIVER PRINCE ALBERT PRINCE GEORGE RED DEER REGINA SASKATOON VANCOUVER VICTORIA

Restrained shrinkage tests to evaluate the cracking potential of the different mixtures were conducted as described in Section 4.10 of the Hardy BBT Limited Phase II report dated December 22, 1989. As of February 12, 1990, when the restrained shrinkage test panels were 3 months old, there was no evidence of cracking in any of the panels. The panels will be inspected intermittently over the next year to see if any cracks develop, but given that they have not yet cracked, it is considered unlikely that future cracking will develop.

In addition to the restrained panel shrinkage tests, Hardy BBT Limited shot restrained ring shrinkage test specimens, which were stored in a 23°C, 50 ± 5% R.H. drying environment in the laboratory. (This work was done as an addendum to the project and does not constitute part of the official contract). No shrinkage cracking developed in any of the specimens in this severe test. In summary, it is apparent that the low water demand, high volume fly ash, high volume polypropylene fibre system has a very low restrained shrinkage cracking potential. This appears to be verified by the 3 month performance reported for the field trials of the system at the Halifax airport.

This report concludes our work on the Supply and Services Contract No. 23440-8-9164/01-SQ. Should you have any queries or require any additional information, please contact the writer.

Yours truly,

Hardy BBT Limited,

Per: D.R. Morgan

D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer.

Reviewed by:

A.J. Kirkness, P. Eng.,
Manager - Materials Engineering Division.

DRM:nmd
Enclosure

cc: Dr. V. Mohan Malhotra,
CANMET

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11 C 1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. J. Humphries

FILE: VA-01584
DATE: 90-02-08
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY: HALIFAX AIRPORT

SUBJECT: FREEZE/THAW DURABILITY TESTING TO ASTM C666, PROCEDURE A

Sample #	Resonant Frequency at 0 Cycles	Resonant Frequency at 300 Cycles	Weight (g) at 0 Cycles	Weight (g) at 300 Cycles	% Wt. Loss at 300 Cycles	Durability Factor %
U1	1950	1920	6933.8	6837.6	1.4	96.9
V1	1647	1600	6609.1	6422.3	2.8	94.4
V2	1642	1606	6651.1	6444.2	3.1	95.7
					Avg: 3.0	Avg: 95.1
W1	1707	1624	6403.5	6295.8	1.7	90.5
W2	1649	1636	6279.5	6192.9	1.4	98.4
					Avg: 1.6	Avg: 94.5
X1	1710	1702	6796.7	6677.1	1.8	99.1
X2	1770	1751	6681.6	6552.9	1.9	97.9
					Avg: 1.9	Avg: 98.5
Y1	1719	1670	6769.2	6620.8	2.2	94.4
Y2	1701	1676	6659.3	6476.9	2.7	97.1
					Avg: 2.5	Avg: 95.8
Z1	1640	1585	6642.1	6487.5	2.3	93.4
Z2	1648	1561	6528.0	6417.7	1.7	89.7
					Avg: 2.0	Avg: 91.6

CERTIFIED BY: D. R. Morgan
D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer.

TECHNICIANS: N. McAskill, A.Sc.T.,
D. Hatch, A.Sc.T.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

TECHNICAL REPORT #A4

TO: SCIENCE & PROFESSIONAL SERVICES DIRECTORATE,
Science Branch,
11C1 Place Du Portage, Phase III,
11 Laurier,
HULL, QUEBEC K1A 0S5

ATTENTION: Mr. John Humphries

FILE: VA-01584
DATE: 90-05-03
CLIENT P.O.
C.C.

PROJECT: SHOTCRETE STUDY - HALIFAX AIRPORT

SUBJECT: FIELD TRIAL MIXES, POLYPROPYLENE FIBRE REINFORCED HIGH VOLUME FLY ASH WET-MIX SHOTCRETE: TEST RESULTS: NOMINAL 480 kg/m^3 CEMENTITIOUS

MIX NO.	X	AVG.	Y	AVG.	Z	AVG.
Compressive Strength 75 mm Dia. Core (MPa)						
@ 7 Days	10.4, 10.0	10.2	9.4, 8.1	8.8	7.4, 7.8	7.6
@ 28 Days	22.8, 24.0	23.4	21.5, 22.6	22.1	18.7, 19.7	19.2
@ 56 Days	25.3, 29.2	27.3	25.6, 25.6	25.6	24.8, 22.3	23.6
@ 91 Days	35.3, 32.6	34.0	32.6, 31.2	31.9	30.3, 29.4	29.9
Compressive Strength 150 mm x 300 mm Cylinders (MPa)						
@ 7 Days	9.8, 9.7	9.8	9.4, 9.3	9.4	6.9, 6.8	6.9
@ 28 Days	26.9, 21.7	24.3	20.0, 20.3	20.2	15.5, 16.1	15.8
@ 56 Days	23.3* 23.6*	23.5	24.3, 25.2	24.8	20.0, 18.5	19.3
@ 91 Days	23.6, 26.7	25.2	25.2, 28.6	26.9	24.9, 22.0	23.5
Flexural Strength, MPa @ 28 Days	3.4,3.4,2.9	3.2	3.4,3.1,3.1	3.2	3.3,2.7,3.3	3.1
Toughness Index @ 28 days						
I_5	-	-	3.0,3.5,3.6	3.4	3.8,3.9,3.5	3.7
I_{10}	-	-	5.4,6.1,6.1	5.9	7.8,7.5,6.4	7.2
I_{20}	-	-	9.1, 11.0, 10.4	10.2	12.8, 13.9 11.8	12.8
Residual Strength, %						
RS (I_5, I_{10})	-	-	48, 52, 50	50	80, 72, 58	70
RS (I_{10}, I_{20})	-	-	37, 49, 43	43	50, 64, 54	56
Boiled Absortion, %	5.1,5.1,5.4	5.2	6.1,5.4,5.8	5.8	6.7,6.8,6.6	6.7
Permeable Voids, %	11.5, 11.5 11.9	11.7	13.3, 12.1 12.9	12.7	14.5, 14.7 14.4	14.5

*Voids of incomplete consolidation in cylinders.

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

VA-01584

September 24, 1990

CANMET
555 Booth Street,
OTTAWA, Ontario
K1A 0G1

ATTENTION: Dr. V. Mohan Malhotra, P. Eng.

Dear Sirs:

RE: Supply and Services Canada Contract No. 23440-8-9164/01-SQ

As requested during our meeting in Ottawa on 90-09-18, enclosed is a recommended mix design for a high volume fly ash, polypropylene fibre reinforced shotcrete for capping pyritic slate outcrops at the Halifax Airport. This mix design is based on the research conducted in the above Supply and Services Canada contract, as reported in the Hardy BBT Limited Phase I report dated October 19, 1989 and Phase II report dated December 22, 1989, and various updating supplementary reports.

We trust this report meets your requirements. Please call if you have any queries, or require any additional information.

Yours truly,

Hardy BBT Limited

Per: D.R. Morgan

D.R. Morgan, Ph.D., P. Eng.,
Chief Materials Engineer

Reviewed by:

A.J. Kirkness, P. Eng.,
Manager - Materials Engineering Division
DRM:lbk
Enclosure
cc: W. John Humphries, Supply and Services Canada

4052 GRAVELEY STREET, BURNABY, BRITISH COLUMBIA V5C 3T6 TELEPHONE (604) 294-3811 FAX (604) 294-4664
GEOTECHNICAL AND MATERIALS ENGINEERING — ENVIRONMENTAL, MATERIALS AND CHEMICAL SCIENCES
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NANAIMO PEACE RIVER PRINCE ALBERT PRINCE GEORGE RED DEER REGINA SASKATOON VANCOUVER VICTORIA

TECHNICAL REPORT

Hardy BBT Limited
CONSULTING ENGINEERING & ENVIRONMENTAL SERVICES

FILE: VA-01584
DATE: September 24, 1990

CANMET,
555 Booth Street,
OTTAWA, Ontario
K1A 0G1

ATTENTION: Dr. V. Mohan Malhotra, P. Eng.

PROJECT: Supply and Services Canada Contract No.23440-8-9164/01-SQ
SUBJECT: Shotcrete Mix Design for Capping Pyritic Slate at Halifax Airport

MIX DESIGNATION: High volume fly ash, polypropylene fibre reinforced shotcrete

Material	Mass (kg)	Bulk Density (kg/m^3)	Volume (m^3)
Cement (Type 10)	170	3150	0.0540
Fly Ash	300	2640	0.1136
Coarse Aggregate (SSD) 10 X 5 mm	460	2707	0.1700
Sand (SSD)	1230	2652	0.4638
Water (Estimate)	145	1000	0.1450
*Polypropylene Fibre	4.5	920	0.0049
Water Reducing Admixture POZZOLITH 344 N	2.3 L	1000	0.0023
Superplasticizer DURASAR	4.7 L	1000	0.0047
Air Entraining Admixture	As required for		
Air Content (as shot)	5±1 %		0.0500
TOTALS:	2316.5		1.0083

Slump - after fibre addition = 100 mm ± 20 mm
Approximate W(C + FA) Ratio = 0.39
Sand Content = Ps = 72.8%
Specified 56 Day Strength = 25 MPa
Plastic Density = 2297 kg/m^3

*Collated, Fibrillated, 38 mm long FORTA CR fibre

DESIGNED BY: D. R. Morgan

D.R. Morgan, Ph.D., P. Eng.
Chief Materials Engineer

Air-Void Parameters - CANMET Results
(Hardy BBT Shotcrete Study - Halifax Airport)

Specimen	Air Content, %	Specific Surface (mm^2/mm^3)	Spacing factor $\bar{L}$, (mm)
Z-1	3.3	46.5	0.138
Z-2	4.4	42.7	0.127
V-1	3.9	24.7	0.218
V-2	3.7	32.1	0.175
Y-1	5.0	19.0	0.258
Y-2	5.0	21.6	0.226
U-2	4.3	14.7	0.333
U-1	4.0	12.8	0.411
W-1	4.9	32.8	0.145
W-2	3.0	31.5	0.195
X-1	4.9	26.4	0.181
X-2	4.0	26.1	0.206

ANNEX-3

REPORT ON INVESTIGATIONS BY COMRIE CONSULTANTS LTD.

comrie

Waste Management Consultants

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

FINAL REPORT

BY:

D. COMRIE CONSULTING LTD.
120 TRADERS BLVD. E
SUITE 209
MISSISSAUGA, ONTARIO
L4Z 2H7

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada.

DSS FILE NO.:	14SQ.23440-8-9171
DSS CONTRACT SERIAL NO.:	23440-8-9171/01-SQ
CANMET PROJECT NO.:	
CANMET SCIENTIFIC AUTHORITY:	V.M. Malhotra and G.G. Carette
DATE OF SUBMISSION:	28-09-90

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1.0 EXECUTIVE SUMMARY

This report summarizes the results of a program to design and test formulations of geopolymeric concretes for use in site rehabilitation work at the Halifax airport. Outcrops of pyritic slate exposed during construction activities have been demonstrated to be responsible for acidic leachate draining into the watershed surrounding the airport.
This leachate has resulted in widespread environmental damage, including mass fish kills. The situation has been under review by Environment Canada in conjunction with Transport Canada for a number of years. As part of these investigations, D. Comrie Consulting Limited (DCCL) was contracted by Supply and Services Canada (SSC) to perform research into formulations of geopolymeric cements.

An examination of the use of various admixtures, including fly ash, silica fume, and conventional aggregates, for incorporation into a cement which could be applied to the Halifax airport slates commenced in December, 1988. The focus of early testing was to assess the effects of the various admixtures on timing of development and ultimate strength of the final product. Assessment of results was initially qualitative; discriminant selection of certain formulations for further testing was accomplished over the following months.

It was found in this initial phase of the program that introducing fly ash at the expense of geopolymer powder likely has a more detrimental effect on strength than ash introduced at the expense of geopolymer liquid. Increasing the concentration of geopolymer liquid (GPA) at the expense of fly ash has a more positive effect on strength than increasing it at the expense of aggregate.

Following the initial examinations, compressive stress testing of selected mixes was undertaken. The results of this work were then selected for application testing using modified shotcreting apparatus. At this time, freeze-thaw prisms and conventional cylinders for compressive stress testing were prepared and submitted to CANMET Laboratories for physical testing using ASTM 666 test procedures.

The submitted prisms failed freeze-thaw testing after 30 cycles. Data pertaining to the mode of failure was not provided. As a result of the prism failure, compressive stress testing was not performed on the shotcreted cylinders.

It was found that, when applied using a shotcrete gun, the geopolymer could be adhered to surfaces of any orientation with no slump occurring.

Concurrent with the physical testing of the submitted material, DCCL continued testing of formulations of geopolymeric cements with the aim of improving reactivity of the material. Following notification of prism failure, a second series of prisms was prepared and submitted to CANMET for freeze-thaw testing. These prisms utilised new formulations of geopolymeric cements, conventional aggregates, and admixtures of silica fume, air entrainer, and super-plasticizers. Along with this testing, the resultant material was subjected to flexural and compressive strength testing.

The geopolymer formulation used in the freeze-thaw prisms was then utilised in a full-scale application using modified shotcreting apparatus. The material was successfully applied to a rock face, a rock ledge, and a section of structural road. Cores taken from this application were subjected to 48-hour compressive strength testing.

The submitted prisms successfully completed freeze-thaw testing in September, 1990. Measurement of temporal variation of physical parameters produced some interesting results, since the change in physical parameters relative to the start of testing reversed itself for some prisms. Reversals can generally be correlated with prisms that had commenced freeze-thaw testing prior to completing a standard 28-day cure period. It is therefore probable that these prisms were still undergoing curing at the time of commencement of freeze-thaw testing.

The Durability Factor of the geopolymer-based prisms returned values ranging from 85 to 104. Discarding those prisms which may have been undergoing curing at the time of freeze-thaw testing, the range of Durability Factors is from 95 to 104. This compares favourably with data obtained in testing of prisms composed of conventional cements and similar admixtures to those used in this study.

Compressive and flexural stress tests performed on prisms from the same series returned values ranging between 26.5 to 30.9 MPa and 3.4 to 4.0 MPa, respectively.

The shotcrete testing indicated that the material could be applied quickly and efficiently using slightly modified shotcreting apparatus. Again, no slump was noted due to the extremely quick set time of the material. Compressive stress tests performed after 48 hours returned values of 34.5 and 36.9 MPa respectively.

The testing and formulation program undertaken by DCCL indicates that geopolymeric concretes behave in a similar fashion to conventional cements. Advantages of geopolymer-based cements include extremely fast set time and very fast development of significant strength. These attributes allow application in areas where minimal service interruptions are desired. Additionally, the lack of slump with the material allows efficient application to capping of surfaces with any orientation.

An analysis of costs associated with a large-scale program to cap exposed outcrops of pyritic slate at the Halifax airport indicates the cost of the product, assuming a mean application thickness of 0.10 metres (0.33 ft), would be \$39.10 per m^2 or \$3.63 per ft^2. Decreasing the mean application thickness by 50% to 0.05 metres would reduce the unit area cost to \$19.55 per m^2, or \$1.82 per ft^2.

2.0 INTRODUCTION

This report summarizes the results of a program to design a mix of geopolymeric concrete to be considered for use as a capping material for outcroppings of pyritic slate at Halifax International Airport. Data pertaining to mix formulations, shotcrete testing, and compressive strength results are presented. A discussion of the results relative to the proposed application will be undertaken.

2.1 PROJECT BACKGROUND

Acid drainage from outcroppings of pyritic slate at the Halifax Airport resulting in large scale fish kills and other environmental damage has been documented since 1960. The slate forms a 2.5 km wide band which stretches through the airport area and carries anomalous concentrations of aluminum, iron, manganese, cobalt, nickel, lead and arsenic. Studies by Environment Canada have shown that blasting and excavation of the slate during the construction of the airport, local highway and other nearby facilities have exposed large areas of rock, producing contamination in local ground and surface water. Acidified groundwater, rich in heavy metals, drains to the nearby Salmon River watershed. Further discussion of the site can be found in Guilcher (1987), Macready (1987) and Worgan (1987).

The situation has been under review by Environment Canada, in conjunction with Transport Canada, for a number of years. Part of Transport Canada's response to the situation has been the construction of a lime treatment facility designed to neutralize the acid drainage from the site. Unfortunately, the lime sludge collected from the treatment facility can also be considered a potential environmental hazard, and poses additional disposal problems.

As part of these investigations, there has been research into potential materials for capping the outcrops to restrict water access and consequent leaching potential of the slate outcrops. A 7 ha waste rock pile has already been capped with clay at a cost of $800,000. Ideal materials for this application require low permeability and high strength to ensure proper capping.

As part of this research, D. Comrie Consulting Limited (DCCL) was contracted by Supply and Services Canada (SSC) to conduct experiments into formulations of geopolymeric concrete with the aim of ascertaining the potential for application of geopolymers to the Halifax Airport problem. The scope and general conditions of the study undertaken by DCCL are described in detail in the initial contract document (Supply and Services Canada, 22.12.88). A copy of the initial contract is included in Appendix 1. Briefly stated, DCCL was contracted to examine different formulations of geopolymeric cement and the use of concrete admixtures such as fly ash, silica fume and slag with geopolyers to create a viable capping material. As part of the study, data pertaining to the mechanical properties (compressive and flexural strength, modulus of elasticity, freeze-thaw durability, thermal expansion coefficients) of the geopolymeric concretes were to be developed. Field testing of the geopolymer to assess the capability for application of mixes by a shotcrete gun was also carried out during this program.

Initially, all work pertaining to the test program was to be performed by DCCL under the supervision of a designated representative of Transport Canada. Subsequent amendments to the initial contract document did not alter the scope of the program; however, the contract amendment of 28 August 1989 assigned testing of geopolymer formulations to the CANMET laboratories under the supervision of the Scientific Authority.

3.0 GEOPOLYMER FORMULATIONS

3.1 GENERAL

Geopolymeric-based concretes have been under investigation by DCCL and associated companies for a number of years. Various formulations have been tested and modified using information acquired through laboratory research and full-scale application in a wide range of environments.

Geopolymeric concretes are based on inorganic binders - cementitous agents which react together to provide high early strength. The term "geopolymer" has been coined to describe these binders, since it is believed that the reactions involved create a polymeric arrangement of inorganic molecules.

Preparation of inorganic binders is carried out by combining liquid and powder portions; blending can be done using conventional cement mixing technology. The thick, viscous liquid which results can then be combined with aggregate to form a geopolymeric concrete. Mix designs can be created to form concretes with consistencies amenable to pouring, extruding or shotcreting. A mildly exothermic reaction in the alkali activated mixture is accompanied by hardening and polycondensation.

The inorganic binder reaction occurs as a result of reacting alumino-silicate oxides with alkali (NaOH, KOH) and soluble alkali polysilicates. It is thought that SiO_4 and AlO_4 tetrahedra result from this reaction and are linked by shared oxygens to form a polymeric network. Positively charged ions, such as sodium, potassium, lithium, calcium or barium, must be present in the framework cavities in order to achieve charge balance (Figure 1).

The ability of binders to resist acidic attack is demonstrated by the performance of solidified material during acid based leachate tests. Waste products containing heavy metals or other toxins have been substituted for aggregate in geopolymeric cements, and then subjected to

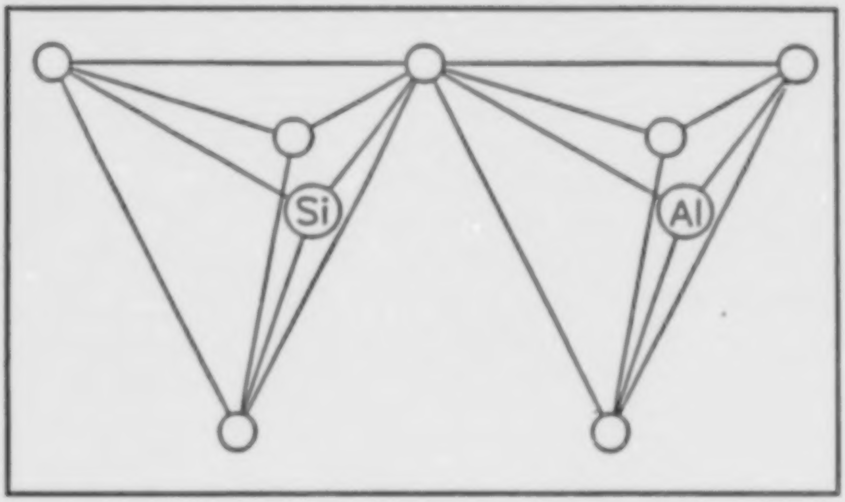


Figure 1: AlO_4 and SiO_4 tetrahedra - basis of the geopolymeric network

leachate tests carried out in accordance with Ontario's Ministry of Environment Regulation 309 guidelines. The guidelines prescribe that samples be first crushed and then subjected to leaching in acetic acid. Concentrations of a range of metals and toxins in the leachate are then measured, and levels compared to maximum effluent concentrations set by the Ministry of Environment.

There is a wide range of wastes which remain bound into geopolymeric cements, even under the conditions dictated by leach testing. This suggests that the binder is capable of resisting the acidic attack encountered in the testing environment.

Throughout this report reference will be made to geopolymers and inorganic binders. Several different compositional designs have been developed for geopolymers during their evolution; these include GP50 and GP52, both of which were used in this work program. DCCL also uses several compositional designs referred to as "inorganic binders" (the term is somewhat more descriptive than "geopolymer"), which were developed on the same principles as geopolymer. Varieties of inorganic binders include IB100 (powder and liquid portions), IB7030 (liquid only), INORBOND and IB dry and liquid activators. Both geopolymers and inorganic binders are proprietary products.

3.2 PHASE 1 PROGRAM

A mix design program for this project was implemented in late 1988, following the assignment of the initial SSC contract. Efforts first focussed on determining the effect of the addition of different constituents, such as clay, fly ash, silica fume and sand, on the nature of a geopolymeric cement. A range of mixtures created with different amounts of these components was created, and evaluated on a semi-qualitative basis.

Following this program, a set of mix designs was used to create hand sample sized cylinders, which were in turn subjected to compressive strength testing at an age of two days. Standard 4x8-inch cylinders were also developed from testing; these cylinders were obtained both during lab scale mix design and from larger scale trials. Data pertaining to mix formulations for this phase of work is presented in Tables 1-7, Appendix 2.

This stage of the program was completed with the fabrication of prisms and 4x8-inch cylinders for freeze-thaw trials and compressive strength testing, respectively.

3.2.1 FREEZE-THAW PRISMS-PHASE I

Preparation of the first prisms to be submitted to freeze-thaw testing was carried out in October of 1989. Six prisms were prepared, in accordance to ASTM 666 specifications; several 8-inch cylinders were also prepared for compressive strength testing. Shotcrete apparatus was used to deliver the geopolymeric cement to both the prisms and cylinders.

The mix design used for the shotcreting of this set of prisms was as follows:

INORBOND 100	
Powder	12.5 weight percent
Liquid	2.5 weight percent
Sand	42.5 weight percent
Pea Gravel	42.5 weight percent

Shotcreting was carried out with the assistance of an outside firm subcontracted to DCCL. Dry ingredients were combined in the hopper of the shotcrete machine, with liquid binder added at the shotcrete gun nozzle. It was found during the work that the cement stiffened almost instantly upon application; slump tests were, of course, impossible.

After the application was completed, the cylinders and prisms were transported from the work site in Kitchener to the offices of DCCL and covered with damp burlap for curing. The burlap covering was periodically moistened over the following 14 days, before the cylinders were transported to CANMET's Material Testing laboratories in Ottawa for freeze-thaw testing. It was agreed that the cylinders be retained by CANMET for testing once the prisms had successfully passed the freeze-thaw trials.

3.2.2 FIELD TRIALS - PHASE I

The field applications which were conducted during Phase I of the program include both pours and shotcreting trials.

The first field application for geopolymer was at the Hope Brook mine, Newfoundland, during the summer of 1988 (DCCL, 1988). Although the application was not funded by this contract, it provides interesting background information, especially since the problem at the minesite was one of acidic drainage.

Hope Brook Mine Application

Water draining into the Hope Brook mine is pumped to surface, through a drainage ditch created by blasting through bedrock, and into a holding pond before pumping to the tailings disposal area. Leaching of sulphide-rich rocks at the minesite means that the drainage water takes on an acidic nature.

By 1988, minesite staff and provincial officials had expressed concern that acid drainage was leaking through the ditch into nearby streams, which in turn drained to a local salmon river. Water monitoring stations between the river and the ditch confirmed the problem. Bags of lime were dumped into local creeks as a stop-gap measure.

Three tonnes of geopolymer (GP50) were brought onto the minesite and mixed with sand and 3/4-inch crushed stone. A minesite cement truck was used for both mixing and transportation of the blend; geopolymer powder and liquid were added first, followed by addition of sand and gravel from the minesite batch plant. A layer of concrete, about 2 to 3 inches in thickness, was applied along a 150 foot section of the ditch. Heavy rains following the application caused flooding of the ditch with about a foot of fast flowing water within 12 hours of the operation. Inspection on the following day showed that the concrete set well in spite of the flooding; test cylinders taken from the pour and tested by Newfoundland Geosciences Ltd. showed compressive strengths of 23.4 MPa.

INORBOND Field Test - Pour Application

Bench scale work conducted in the Halifax Airport program was followed by a field test using an IB100 based concrete during April of 1989. Binder, sand and 3/4-inch crushed gravel was blended outdoors in an electric powered portable cement mixer; the outside temperature was about 55 °F. After approximately five minutes of blending, the mix was poured into molds for bricks (4x8x2-inch), flagstones (18x18x2-inch) and standard 4x8-inch concrete testing cylinders.

A piece of steel re-bar was inserted into one cylinder; in spite of the cool temperatures, the re-bar could be used to pick the cylinder up within half an hour. Bricks and flagstones were de-molded half an hour after pouring.

INORBOND Field Test - Shotcrete Application

Geopolymeric cement was first shotcreted in October of 1989 during the preparation of Phase I freeze-thaw prisms. A more thorough examination of the use of shotcreting technology for the application of geopolymer was carried out in December of 1989. This work, coordinated with an outside firm subcontracted to DCCL, involved the application of approximately 120 kg of an INORBOND-based mortar. The mix design used is as follows:

INORBOND A (7030 liquid)	10kg
INORBOND B (powder)	60kg
Water	20kg
Pea gravel	180kg
Concrete Sand	180kg

Concrete sand, INORBOND powder and liquid were all combined in the shotcrete hopper and pumped approximately 10m to the application area.

This field test proved to be a dramatic demonstration of how the use of high-pressure shotcreting equipment can minimize the setting time of a geopolymeric concrete. In fact, it was found that the INORBOND mortar set almost instantly after application. Using a wall-mounted plywood board as a target, the shotcrete operator was able to construct a 2-inch thick coating over the vertical surface of the board, as well as creating 6-inch diameter cylindrical mounds which protruded up to 18 inches from the wall, with their long axis oriented parallel to the floor. Cylindrical mounds up to 36 inches in length were also constructed using the floor as a base instead of the plywood. A quantity of the mortar mixture was also applied to a wire framework hung from the ceiling - the result was a suspended layer of shotcrete.

Iron Hydroxide Sludge Solidification

Samples of the iron hydroxide sludge produced by the Airport on-site lime treatment facility were provided by Paul Goudey at the Halifax Airport. Although solidification of the sludge was not a focus of this program, it is significant to note that a preliminary program was successful in solidifying the sludge using a variety of geopolymer-based mix designs. The mix designs, which also incorporate sand and fly ash, can be found in Table 7. Three solidified samples were returned to Mr. Goudey, with a recommendation that they be subjected to leachate testing in order to evaluate the effectiveness of the geopolymeric mix.

3.3 PHASE 2 PROGRAM

The Phase 2 program commenced in early 1990. At that time, additional laboratory testwork into geopolymer formulations was undertaken with the aim of improving reactivity, cure time, timing of development of significant early strengths, and improving the ultimate strength of the geopolymer. Following evaluation of the results, the final product of this phase of experimentation was submitted to Transport Canada for freeze-thaw testing.

In order to complete Phase 2 testing, the geopolymer formulation was tested in a full-scale trial involving application of the material by shotcrete gun. Cores taken from these trials were subjected to compressive strength testing to evaluate the timing of compressive strength development.

3.3.1 FREEZE-THAW PRISMS-PHASE 2

Preparation of prisms for freeze-thaw testing commenced in June, 1990. Two sets of six prisms were poured. In each set, the prisms were prepared as six separate batches. The use of separate batches was deemed necessary due to the speed with which the mix became too viscous to pour. A total of five prisms, 2 from the first set and three from the second set, were submitted to CANMET for testing.

The preparation of the prisms was performed in accordance with ASTM 666 standards. Table 8 summarizes the constituents of the mixes.

Mixing of the material for testing was done at DCCL using a Lightnin mixer with a capacity of 0.02 m^3. After pouring, the prisms were trowelled and covered by plastic. The prisms were allowed to attain surface solidification prior to relocation to a storage area. The prisms were demoulded at a variety of different times to assess how this may affect the behaviour of the Inorbond. Table 9 summarizes the surface solidification times and dates of prism pouring and demoulding. Following demoulding, the prisms were completely wrapped in plastic and returned to storage. Submission of the prisms to CANMET was completed on July 13, 1990.

Assessment of slump for each of the mixes was not performed. The omission of this test was for practical reasons; the material underwent liquid-solid phase transition too quickly for slump to occur.

TABLE 8. COMPOSITION OF FREEZE-THAW PRISMS SUBMITTED TO CANMET

PRISM	INORBOND 700 (kg m^{-3})	INORBOND 7822 (kg m^{-3})	SILICA FUME (kg m^{-3})	SAND (kg m^{-3})	COARSE AGG. (kg m^{-3})	A.E.A* (l m^{-3})	SPN** (l m^{-3})
COM-1	425	500	75	1000	----	0.330	0.825
COM-2	425	500	75	1000	----	0.330	0.825
F2-1	450	530	80	715	285	0.300	0.420
F2-2	450	530	80	400	600	0.260	0.900
F2-3	450	530	80	200	800	0.300	0.420

* Air Entrainer
** Super Plasticizer

TABLE 9. SURFACE SOLIDIFICATION, DATE OF PREPARATION AND DATE OF DEMOULDING

PRISM	SURFACE SOLIDIFICATION (minutes)	DATE POURED	DATE DEMOULDED
COM-1	10.2	07.06.90	20.06.90
COM-2	9.5	07.06.90	20.06.90
F2-1	4.5	24.06.90	26.06.90
F2-2	6.0	28.06.90	29.06.90
F2-3	4.2	30.06.90	04.07.90

3.3.2 SHOTCRETE TRIALS-PHASE 2

Subsequent to the Phase 1 shotcrete trials, a second larger scale trial was performed in early July, 1990, by DCCL and another outside firm. For this test, a total of 1,000 kg. of INORBOND and 4,000 kg. of locally available aggregate was applied to a rock face, a rock ledge, and to a road surface.

The dry materials were mixed in a 7 m^3 cement mixer and dumped directly into the shotcrete hopper. The material was then auger fed to the pressurization chamber. The dry material was driven through a 12-metre length of 7.6 cm hose at an average pressure of 1340 KPa (see Plates I, II, III and IV).

Addition of the INORBOND liquid was accomplished at the nozzle of the shotcrete apparatus using an air-driven Sandpiper pump. The amount of liquid introduced to the dry mixture was controlled by the operator using a standard faucet.

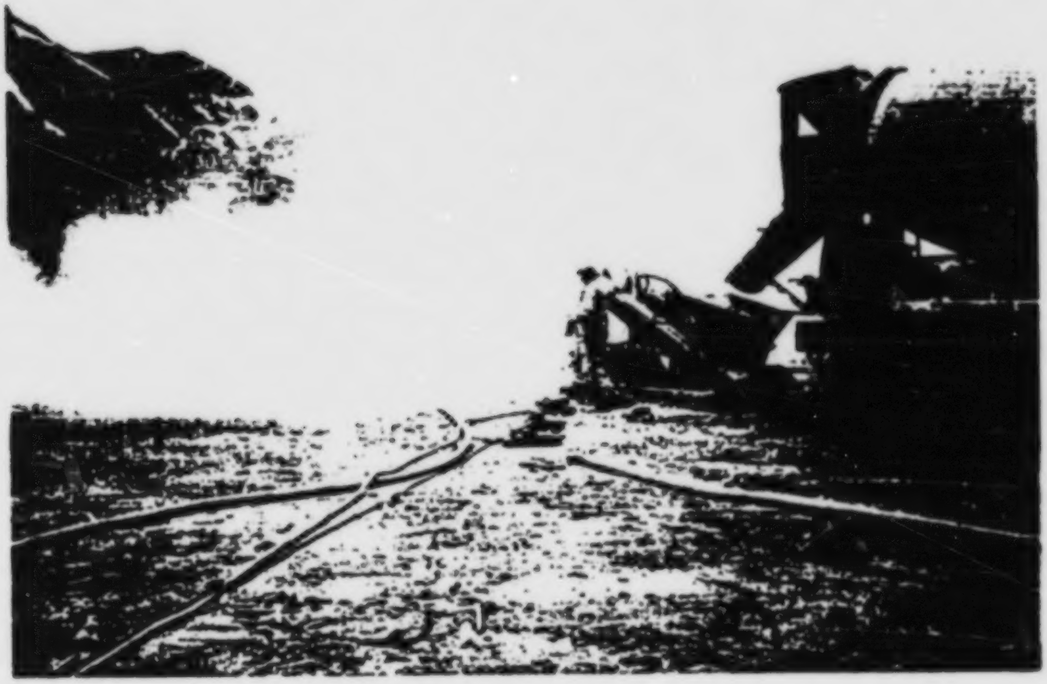


Plate 1: Phase II Shotcrete Program. General view of shotcrete feed apparatus.

Plate 2: Phase II Shotcrete Program. Shotcreting of 19 m^2 section of structural road. Small diameter hose is used for delivery of liquid.

Plate 3: Phase II Shotcrete Program. General view of completed section of structural road.

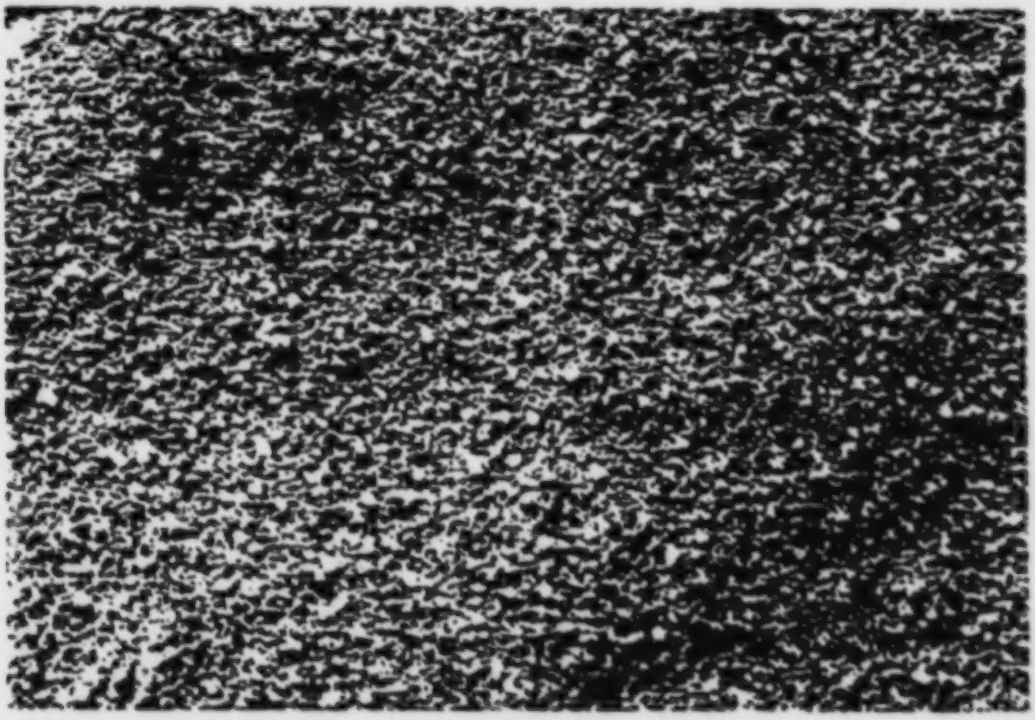


Plate 4: Phase II Shotcrete Program. Detailed view of shotcreted road section. Horizontal width is approximately 20cm.

4.0 TESTWORK

4.1 PHYSICAL TESTING PHASE 1

Physical testing during Phase 1 was carried out in several stages. First, the initial mix designs were subjected to a semi-qualitative evaluation (Tables 1a and 1b, Appendix 2), in which samples were rated on a scale of 1-5 (5 being the highest, or most favourable) for thickness of the mix, setting time, surface cracking, 1-day hardness and 7-day hardness. The goal of the program was to identify formulations which could be easily handled, set up within a period of a few hours, achieved high hardness within 1 day and exhibited good surface characteristics. Additional testwork focussed on the use of high fly ash contents was also carried out, using more subjective evaluations.

The second stage of testing can be considered more quantitative, since samples were submitted to Golders Associates of Mississauga for compressive strength testing, in accordance with CAN 3-A23.2-14C M77. Two types of molds were used to create the specimens for compressive strength testing - standard 4x8-inch molds, and smaller, hand sized cylinders.

As discussed in an earlier section, Phase 1 concluded with the preparation and submission of prisms and cylinders to CANMET's Material Testing laboratories for freeze-thaw testing. Since it was found that the prisms submitted for testing failed ASTM 666, it was decided not to go ahead with compressive strength testing of the cylinders provided.

4.2 PHYSICAL TESTING-PHASE 2

4.2.1 FREEZE-THAW PRISMS

The relevant data pertaining to the 5 prisms submitted to CANMET for freeze-thaw testing are presented in Table 10. Relevant physical parameters were measured at 0, 150, and 300 cycles of freezing and thawing.

4.2.2 PHASE 2 SHOTCRETE TRIALS

Experimentation with the liquid feed indicated that optimum results were obtained when the mixture achieved a slightly moist consistency at the nozzle. Problems encountered with the machinery and inefficient delivery of shotcrete mix to the nozzle required the use of larger amounts of liquid than had originally been planned for in order to achieve this consistancy.

During application of the shotcrete, surface solidification times were noted for the mixture. It was found that initial solidification times ranged from 1.5 to 5 minutes. Observations of the shotcreted material over the ensuing 48 hours (after application) were made to assess the curing process and to ascertain the presence or absence of surficial micro-fracturing which may be expected to occur when working with quick set concretes.

TABLE 10. MEASURED PHYSICAL DATA FOR 5 PRISMS SUBMITTED TO CANMET

# OF CYCLES	WEIGHT (kg) 0	WEIGHT (kg) 150	WEIGHT (kg) 300	LENGTH (mm) 0	LENGTH (mm) 150	LENGTH (mm) 300	LONGITUDINAL FREQUENCY ($m\ s^{-1}$) 0	LONGITUDINAL FREQUENCY ($m\ s^{-1}$) 150	LONGITUDINAL FREQUENCY ($m\ s^{-1}$) 300	ULTRASONIC PULSE VELOCITY ($m\ s^{-1}$) 0	ULTRASONIC PULSE VELOCITY ($m\ s^{-1}$) 150	ULTRASONIC PULSE VELOCITY ($m\ s^{-1}$) 300
COM-1	6.077	6.004	5.957	363.4	363.5	363.5	3660	3664	3640	3236	3285	3285
COM-2	5.910	5.876	5.837	363.1	363.2	363.2	3696	3674	3670	3209	3247	3247
F2-1	6.514	6.380	6.274	363.4	363.7	363.7	3645	3630	3710	3368	3465	3395
F2-2	6.327	5.998	5.900	362.7	362.8	362.8	3490	3490	3266	3577	3462	3425
F2-3	6.480	6.493	6.430	363.4	363.9	363.9	3385	3430	3120	2819	3302	3365

5.0 RESULTS

5.1 PHASE 1 WORK

As previously noted, the detailed results of geopolymer formulations relevant to the Phase 1 testwork are included in Appendix 2. Progress reports submitted to SSC during the Phase 1 testwork are included in Appendix 3. Of particular note are the following results:

1) During the first work to address the behaviour of geopolymer and inorganic binder with other reactive and non-reactive constituents, products of different mix designs were evaluated on the basis of viscosity, set time, cracking and hardness. Optimum product was produced by mixes 10-25-2, 10-25-5, 11-10-5, 11-25-1, 11-25-2, 11-25-3 and 11-25-4 (Appendix 2, Tables 1a and 1b). These mixes used either Inorbond or geopolymer as an activator. Specifically, the mixes included amounts of Type D Inorbond, slag, silica fume, calcium hydroxide, IB Liquid Activator and caustic; each mix contained approximately 60 weight percent sand. A comparison of samples 11-10-5, 11-25-1 and 11-25-2 suggests that the concentration of caustic used and the use of calcium hydroxide are not critical to the physical characteristics of the product.

2) Qualitative evaluation was also made of a range of samples which incorporated large amounts of fly ash (Tables 2 and 4). Moldability, hardness and binder requirements were used as evaluation criteria. This work is the subject of an interim report appended in Appendix 3; geopolymer contents were reduced to between 13.5 weight percent (for minimal strengths and longer curing times) and 18.1 weight percent (ideal physical characteristics). During the program, several observations regarding constituents were made:

   Fly Ash - absorptive characteristics of course require higher binder contents with increased ash content; using sufficient addition of binder, mixes could be created (without forsaking hardness and moldability) with up to 54 weight percent fly ash.

   Clay - clay was found to contribute significantly to moldabilty.

   Silica Fume -silica fume appeared to contribute to hardness, ease of mixing and moldability, although water contents had to be increased as a result of its use.

   Water - amounts of water used are critical, with as little as 5 weight percent making a dramatic difference in the nature of the mix.

3) The relationship between Type F Inorbond powder, liquid and cement is examined in Tables 4(c), 4(d) and 4(e); setting times increase with decreasing cement or increasing liquid contents.

4) Compressive strength testwork for Phase I is summarized in Tables 5(a), 5(b) and 5(c); some points are graphically represented in Figures 2 through 6. Several conclusions can be drawn from this data, including:

    - That strength increases with the proportion of coarse aggregate (Figure 2) and decreases with increased use of fine aggregate (sand). This is, of course, as expected.
    - That the length:diameter ratio of cylinders used for testing does not appear to show correlation with compressive strength (Figure 3). This suggests that comparisons can be made among the small hand sized cylinders with low length:diameter ratios.
    - That compressive strength increases slightly with density (Figure 4). This relationship could reflect any number of factors, including the ability of more dense coarse aggregate to lend strength to the mix.
    - That, in the ranges examined, introducing fly ash at the expense of geopolymer powder (GPB) may have a more detrimental effect on strength than introducing ash at the expense of geopolymer liquid (GPA), as shown in Figure 5(b).
    - That, in the ranges examined, increasing the concentration of geopolymer liquid (GPA) at the expense of fly ash has a more positive effect on strength than increasing it at the expense of aggregate (Figure 5b). This seems logical, since aggregate likely contributes to strength to a greater degree than fly ash.
    - cements can attain approximately 25% of a 31 day 33.6 MPa compressive strength during their first 3 days of curing and 60% after 7 days (Figure 6). Water has a dramatic effect in cutting strengths.

5) The Phase I freeze-thaw prisms submitted to CANMET underwent structural failure after 30 cycles of freezing and thawing. The mode of failure was not determined.

6) Field trials have indicated that some geopolymeric cements can set in spite of cold temperatures (50 °F range) or in spite of immersion in water shortly after pouring.

Figure 2: Coarse Aggregate Content
vs Compressive Strength

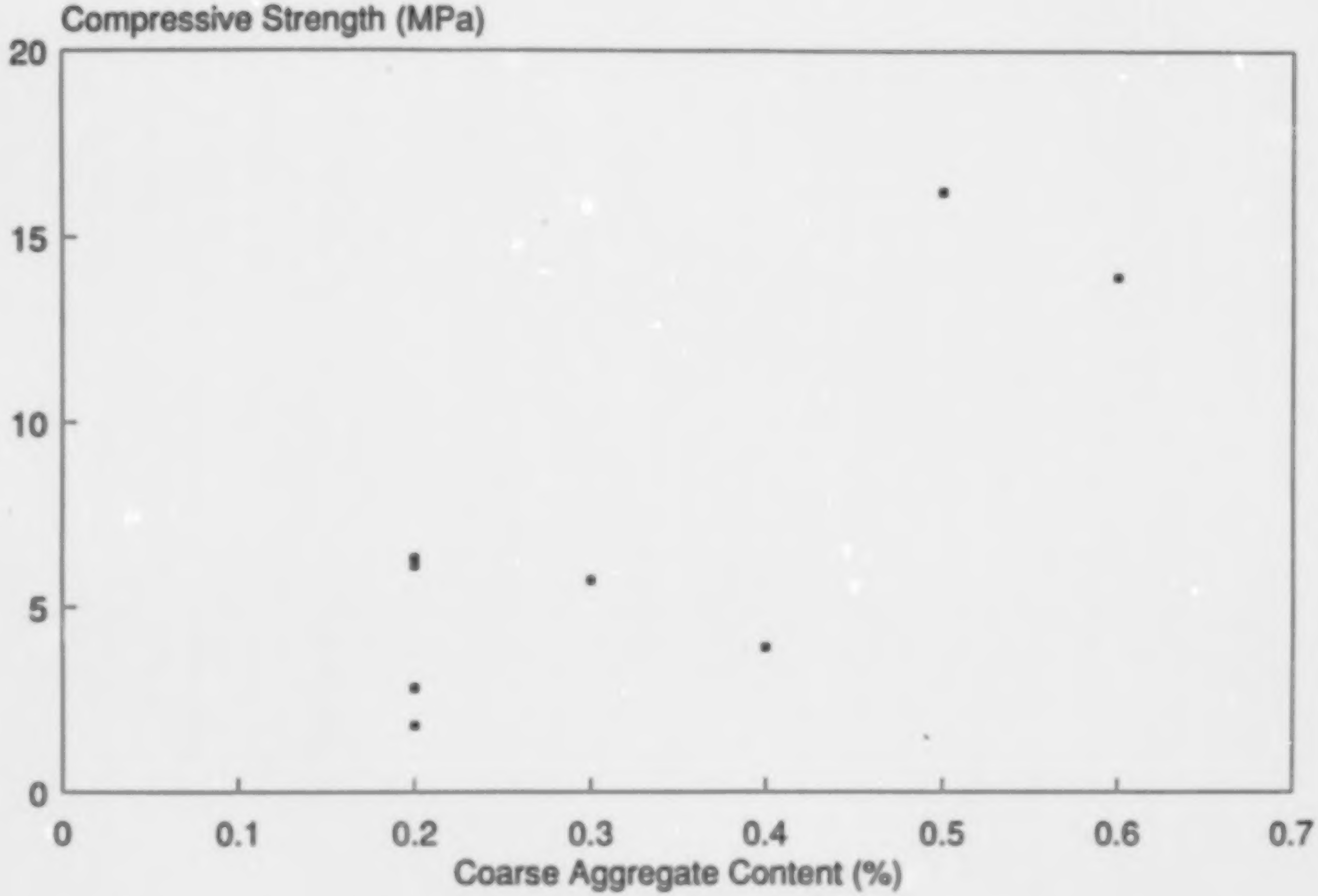


Figure 3: Length:Diameter Ratio vs Compressive Strength

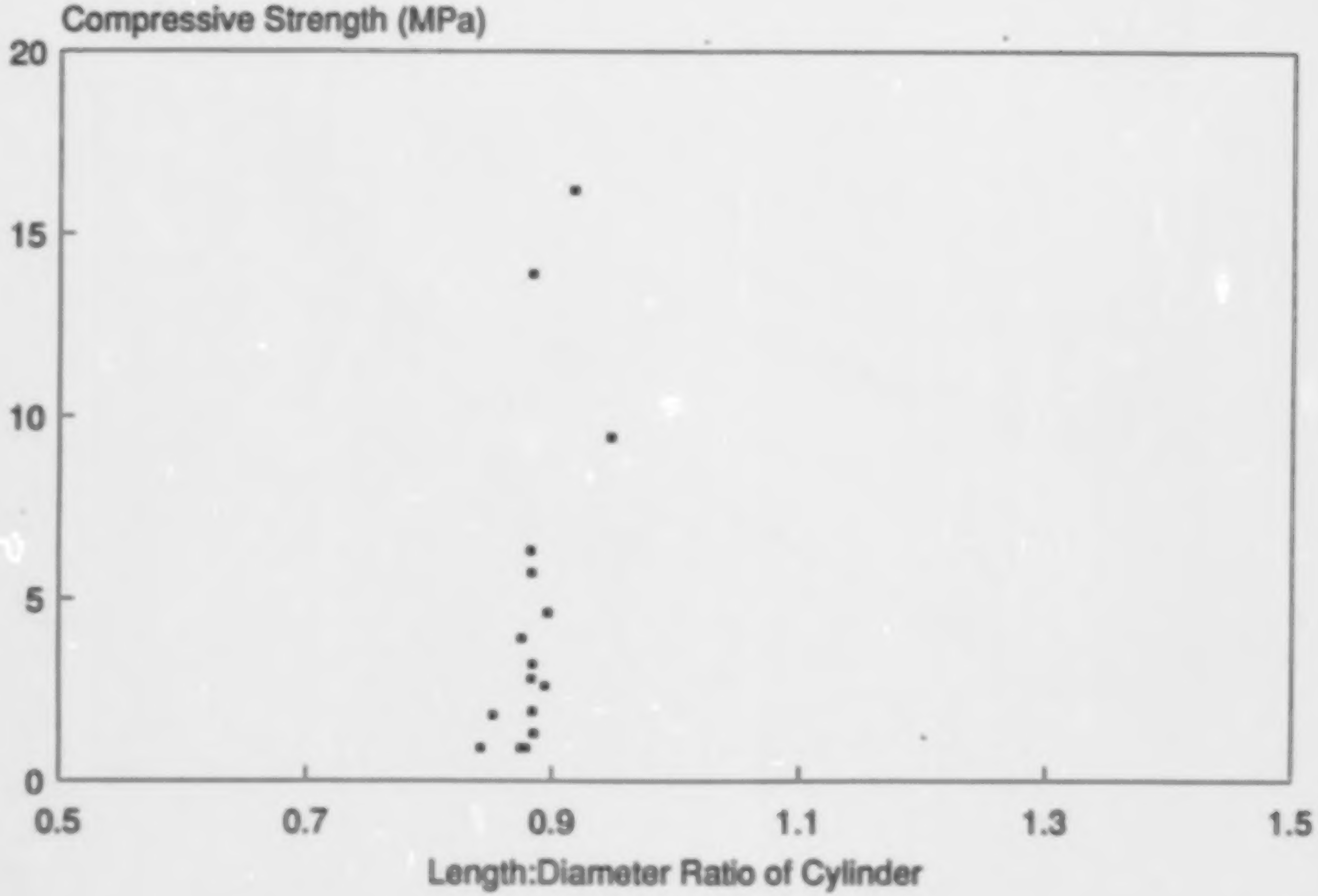


Figure 4: Density vs
Compressive Strength

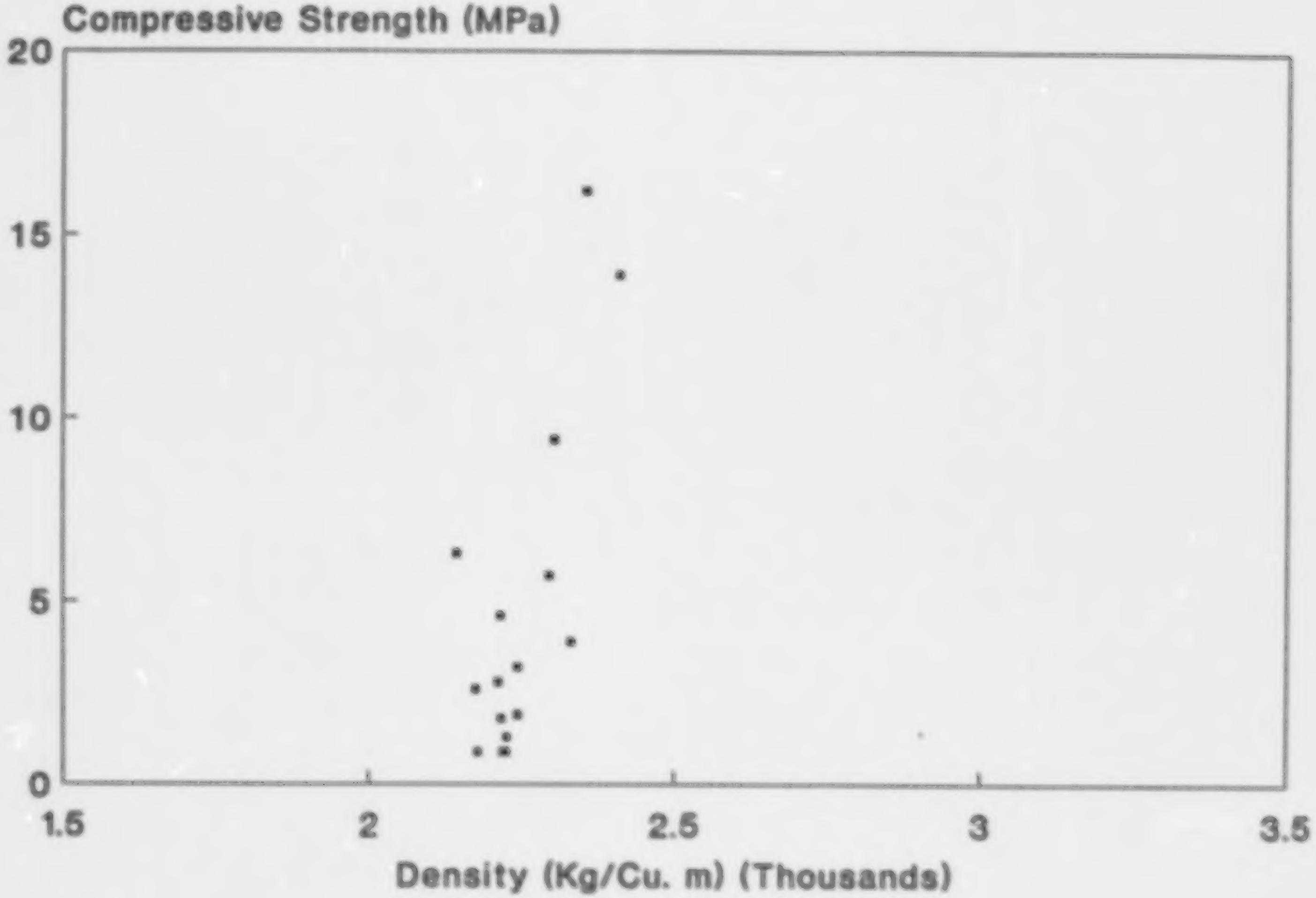


Figure 5(a): Fly Ash Content vs Compressive Strength

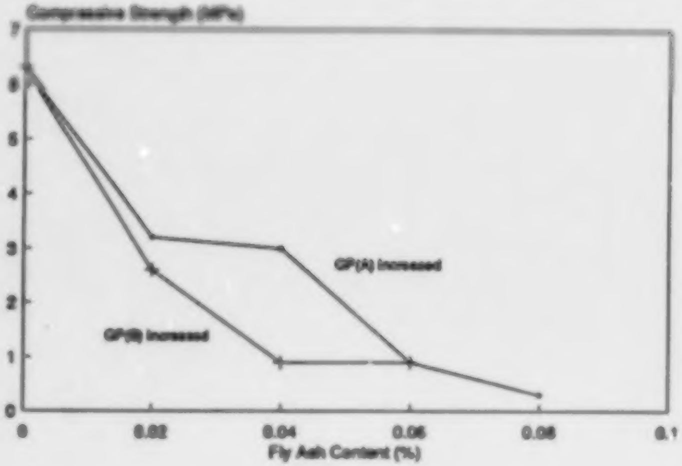


Figure 5(b): GP(A) Content vs Compressive Strength

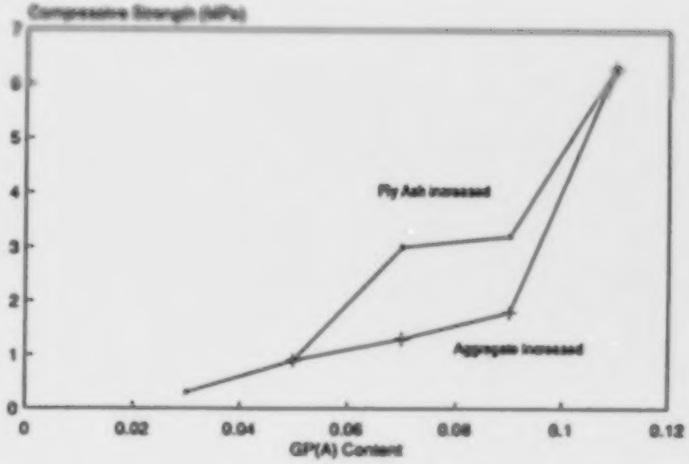
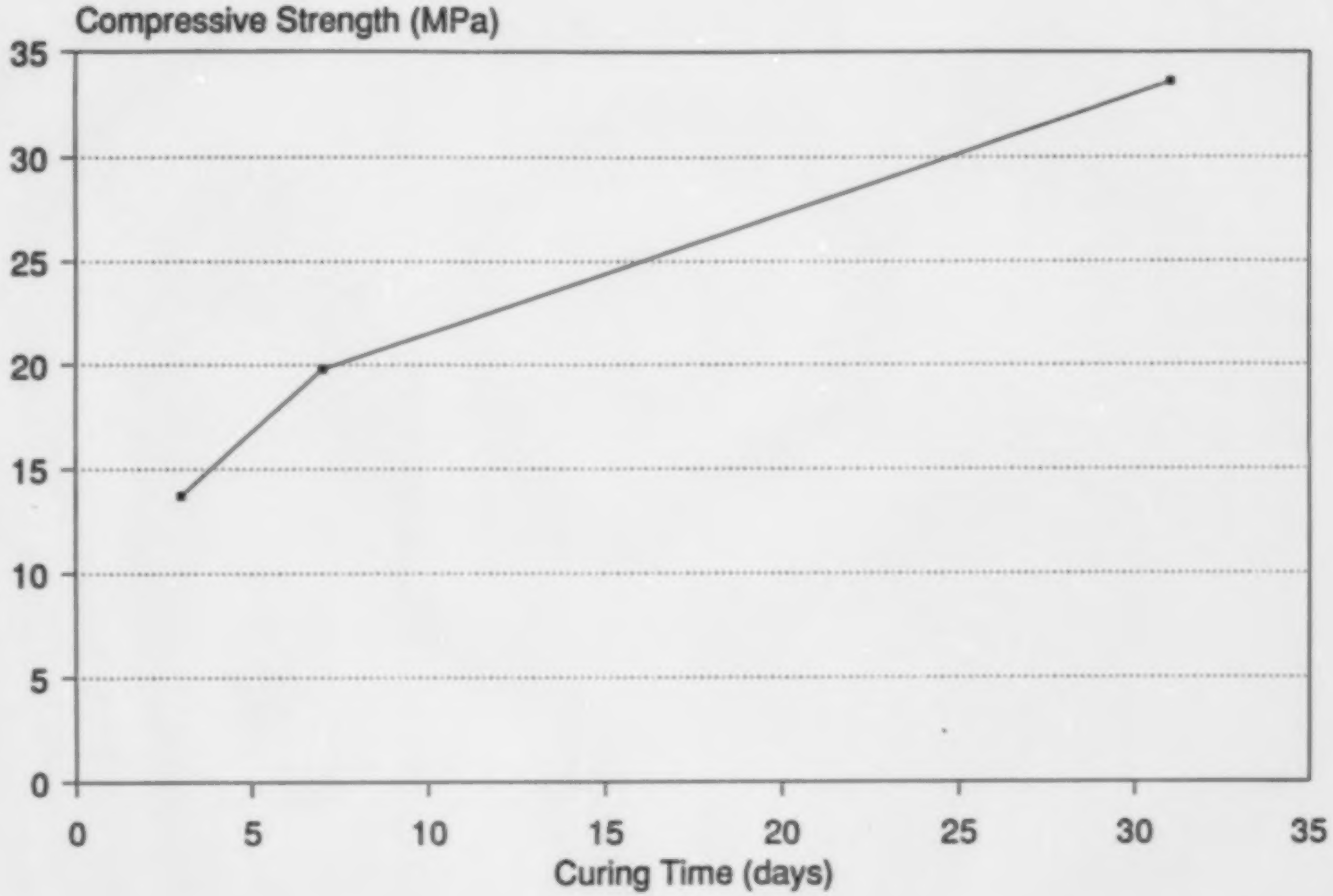


Figure 6: Change in Strength over Time
(sample 4-7-2)



7) In trials with a shotcrete gun, it was found that the material responded well with minimal slump and almost instantaneous set-up. The trials also resulted in the re-design of a shotcrete gun to allow introduction of INORBOND liquid to INORBOND solid at the nozzle. Optimum results for shotcreting were attained using this method.

8) Earlier work showed that the iron hydroxide sludge from the lime treatment facility could be successfully solidified by a geopolymeric binder. To our knowledge, leach tests were not performed on the samples.

9) Compressive strength tests (Table 5b, sample 4-7-2) on shotcreted cylinders by Golder Associates show that strengths of 13.7 MPa were reached in three days. Strength continued to increase to 33.6 MPa, after a curing period of 31 days.

10) Lower 31-day strengths (9.4 MPa) were achieved by a sample (4-7-2a) from a similar mix poured on the same day as the tested shocrete cylinders. In this case, water was added.

5.2 PHASE 2 WORK

5.2.1 FREEZE-THAW TESTING

The measured data for freeze-thaw testwork are summarized in Table 10 (Sec. 4.2.1). From this data, the changes in physical parameters of the prisms are calculated. Table 11 summarizes this data.

Calculations of the dynamic modulus of elasticity and the durability factor for each prism after 300 cycles of freezing and thawing are shown in Table 12.

TABLE 12. MODULUS OF ELASTICITY AND DURABILITY FACTORS AFTER 300 CYCLES

PRISM	MODULUS OF ELASTICITY (MPa)			PERCENT CHANGE	RELATIVE DYNAMIC MODULUS OF ELASTICITY (%)	DURABILITY FACTOR (%)
CYCLES	0	150	300	300		
COM-1	16275	16065	15720	-3.4	99	99
COM-2	16130	15850	15720	-2.5	99	99
F2-1	17300	16750	17240	-0.3	104	104
F2-2	15375	14550	12550	-18.4	88	88
F2-3	14825	15150	12550	-15.3	85	85

TABLE 11. CALCULATED DATA FOR THE FREEZE THAW PRISMS

A. ABSOLUTE VARIATIONS

	WEIGHT (kg)		LENGTH (mm)		FREQUENCY (Hz)		VELOCITY ($m\ s^{-1}$)	
CYCLES	150	300	150	300	150	300	150	300
PRISM								
COM-1	-0.074	-0.120	+0.065	+0.086	+4	-20	+49	+49
COM-2	-0.034	-0.073	+0.055	+0.065	-22	-26	+38	+38
F2-1	-0.134	-0.240	+0.283	+0.303	-15	+65	-3	+27
F2-2	-0.329	-0.427	+0.085	+0.099	0	-224	-15	-52
F2-3	0.013	-0.050	+0.534	+0.604	-55	-265	+483	+54

B. PERCENTAGE CHANGES

	WEIGHT		LENGTH		FREQUENCY		VELOCITY	
# OF CYCLES	150	300	150	300	150	300	150	300
PRISM								
COM-1	-1.22	-1.97	0.02	0.02	0.1	-0.5	0	-1.51
COM-2	-0.58	-1.24	0.02	0.02	-0.6	-0.7	1.18	1.18
F2-1	-2.06	-3.68	0.08	0.08	-0.4	1.8	2.88	0.80
F2-2	-5.20	-6.75	0.02	0.03	0	-6.4	-3.21	-4.25
F2-3	+0.20	-0.77	0.15	0.17	-0.1	-7.8	17.13	19.37

90-day flexural testing on 2 prisms from the COM series of prisms returned values of 3.4 and 4.0 MPa. In addition, a 90-day compressive stress test performed on a "F" series prism returned values of 30.9 and 30.0 MPa for two cubes cut from the prism.

5.2.2 PHASE 2 SHOTCRETE TRIALS

As noted in Sec. 4.2.2, surface solidification times ranged from 1.5 to 5 minutes. No slump was noted to occur. No surficial cracking of the material was observed. Coring of a section of structural roadway using a compressed air driven hand drilling apparatus was performed 24 hours after the shotcrete was laid down. It was found that coring of the material was extremely difficult due to the hardness of the material. After 2 hours of labour, 6 cores ranging from 5 to 9 cm. in length were obtained. Two of the cores were submitted for compressive stress testing. The 48-hour strength obtained for the cores was 36.8 and 34.5 MPa respectively.

6.0 DISCUSSION

The field trials conducted prior to and during the Phase I program provided some interesting information. It was shown during the Hope Brook work that conventional mixing technology (i.e., a standard cement truck) could be used to assist in the application of the binder. This application also showed that exposure of the cement to running water a few hours after application had no discernable effect. The field scale pour trial with a geopolymeric cement showed that a mix could be successfully used at temperatures of 50 ^{0}F, and cylinders taken during the pour showed increasing compressive strengths up to 33 MPa over one month. The first shotcreting trials provided dramatic information, demonstrating that the binder sets extremely rapidly, and with minimal amounts of binder liquid portion, when applied under high pressure.

Although no leach tests were conducted on the iron hydroxide sludge, it is worth noting that the sludge was successfully solidified. This area could be a focus of future work.

Testwork conducted in Phase I with various fillers, activators and aggregates provided information which could be useful for developing mixes for specialized applications. Fly ash did not prove to be as valuable as aniticipated, as it seems to create a significant loss in strength and also require higher amounts of binder. Silica fume contributes to ease of mixing, which can be valuable, and clay provides increased moldability. Proportions of water in the mix proved to be critical; the addition of a few percent too much water can have disastrous effects on strength.

Compressive strength tests were conducted on a number of hand-sized cylinders after curing periods of 2 days. It should be noted that Golders Associates cautions that the true strengths of samples from these non-standard cylinders may be different than those reported. In response to this concern, two cylinders, one hand sized (2-7-2) and another a 4x8-inch standard cylinder (2-7-2a), both created from the same mix design, were compared. The strength for the large cylinder was over twice the strength obtained for the hand cylinder, suggesting that our reported strengths for this series may be considerably less than actual strengths. A chart of length:diameter ratios for the small cylinders indicated that minor variation in ratios had no effect on strength. Thus the strengths of the hand sized-cylinders have only been used for comparison with each other, rather than for comparison with "real world" situations.

Included among the conclusions which can be reached from the strength testing was that fly ash added at the expense of binder of course resulted in some loss of strength; strength loss was greater when ash was added at the expense of geopolymer powder than at the expense of liquid.

There is a wide variability in the results obtained from freeze-thaw testing of the Phase 2 prisms composed of INORBOND, conventional aggregates, and concrete additives. The measured variations appear both when comparing temporal and final results obtained for all prisms tested and when reviewing data relevant to individual prisms. The most uniform physical data sets for the prisms include the COM-1 and COM-2 prisms. All prisms tested underwent surface scaling ranging from moderate to severe (Carette, 1990).

A possible explanation of the widely variable temporal physical changes observed for the different prisms is that the prisms had not completely cured at the initiation of freeze-thaw testing. In support of this, the data presented in Table 9 (Sec 2.3.1) shows the dates of preparation of the various prisms. Assuming that testwork commenced within one week of submission to CANMET, the final three prisms poured had not completed a standard 28-day cure period prior to the commencement of freeze-thaw testwork. It is therefore probable that the prisms were still undergoing curing at the time of testwork. Accordingly, the prisms returning the most uniform physical data (COM-1, COM-2) represent those that had undergone a standard 28-day cure period. The temporal variations of physical properties for the individual prisms are shown in Figure 7.

Contradictory test results obtained from the temporal measurement of longitudinal frequency variations are emphasized with the COM-1 and F2-1 prisms. In addition, the measured temporal increase in pulse velocity for the COM-2 and F2-3 prisms also appears unusual.

Survival of the INORBOND prisms created for the purpose of the Halifax International Airport study indicate the material has acceptable durability. Additionally, the fast preliminary cure and final set times observed for both shotcreted material and prism pouring are considered valuable assets for ensuring that the application of the material to surfaces of varying orientations is successful.

The freeze thaw results of the Inorbond prisms compared to the results obtained by Malhotra and Giaccio (1987) are favourable. Figures 8-11 are comparison graphs of the physical changes for the INORBOND prisms relative to the prisms created for the Malhotra and Giaccio (1987) study. Similar percentage variations with respect to length change, velocity change, frequency change, and weight change are noted, in all cases, for 3 out of the 5 INORBOND prisms tested. The condition of surface scaling for freeze-thaw tested prisms was also noted by Malhotra and Giaccio (1987).

The ability for INORBOND to be applied using a shotcrete machine was demonstrated in both the first and second phases of the testing program. Plates 1-4 (Sec 2.3.2) illustrate the application of INORBOND with a shotcrete gun to a section of structural road surface and the resultant texture of the material following application. The high compressive strengths

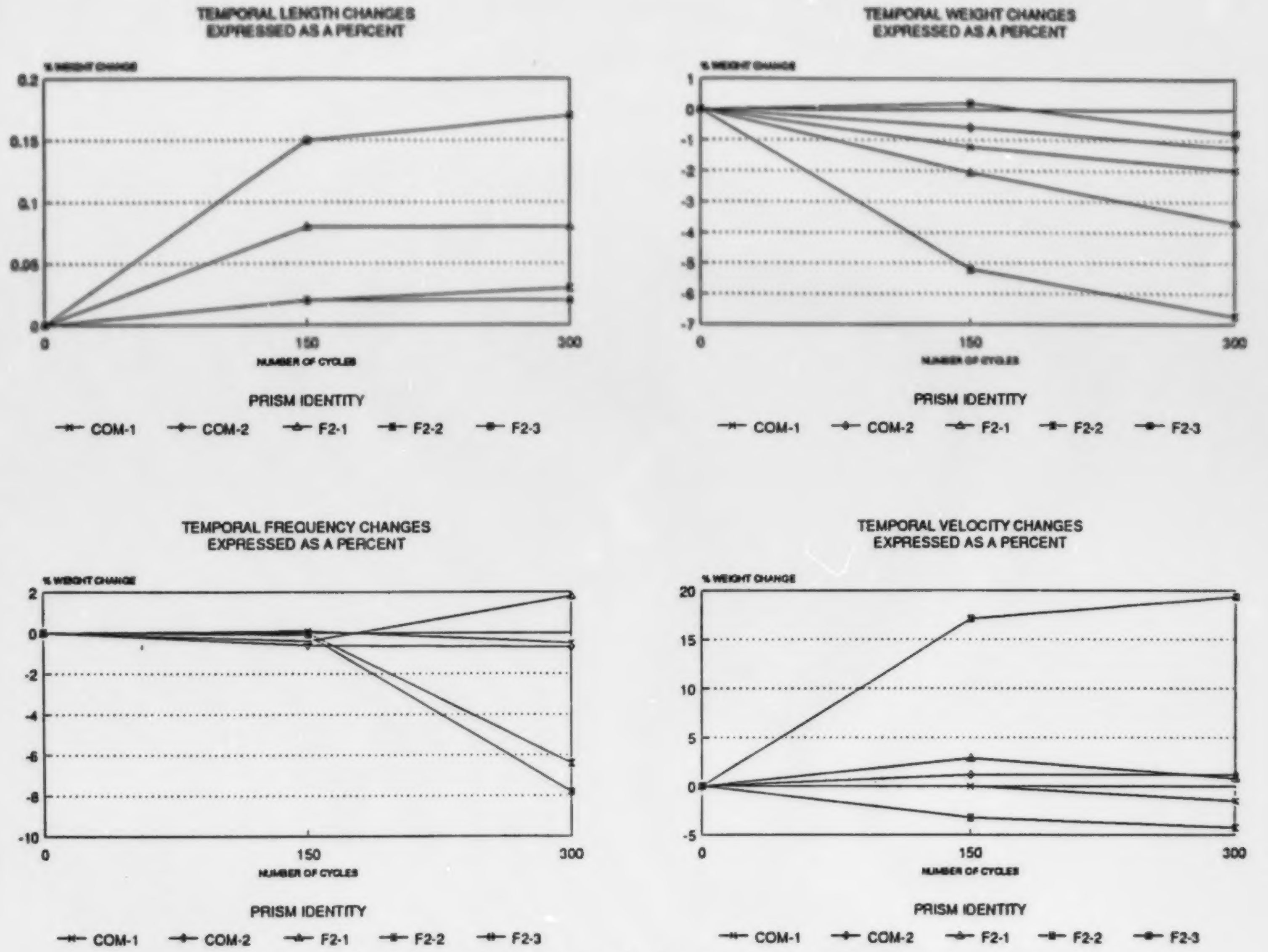
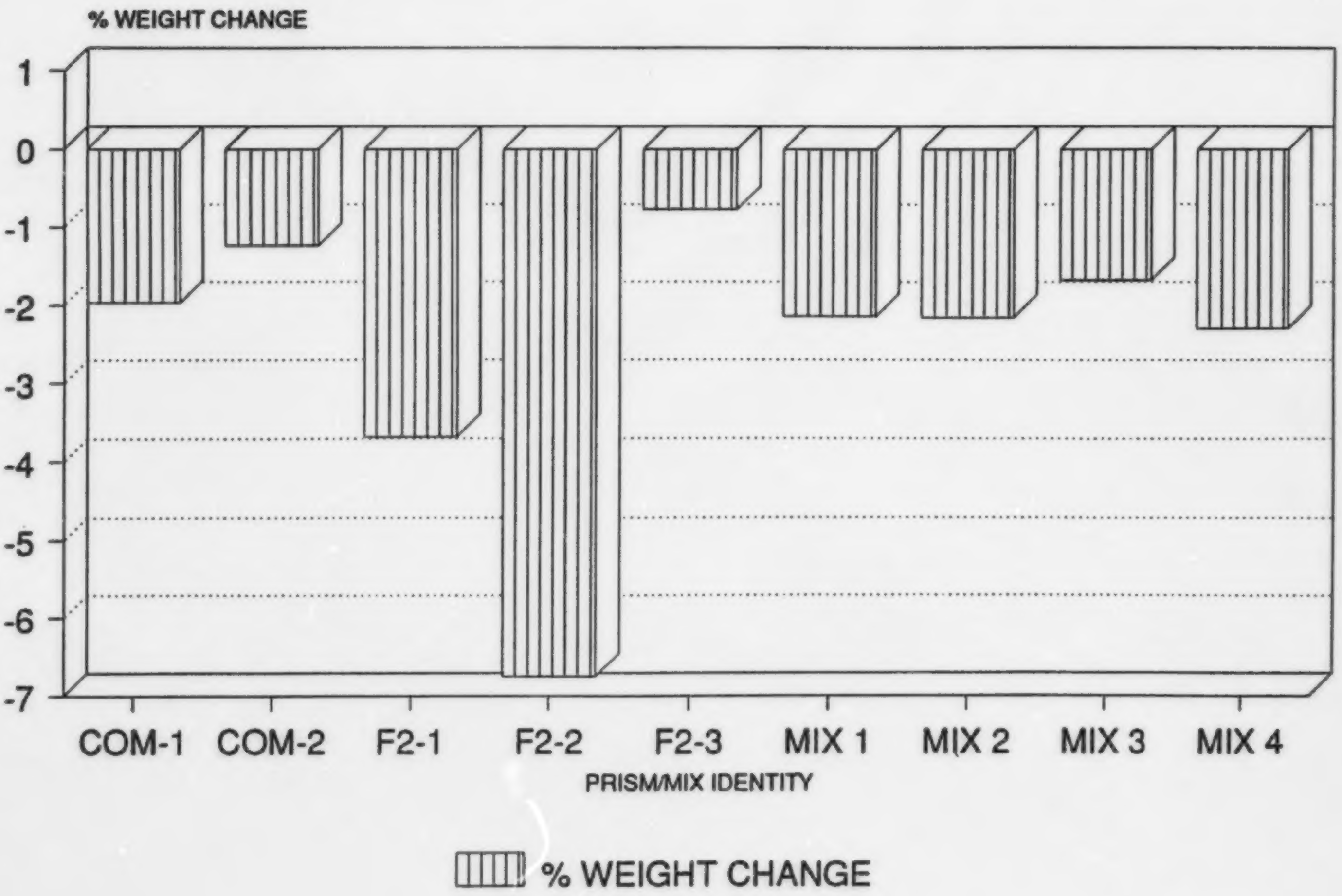


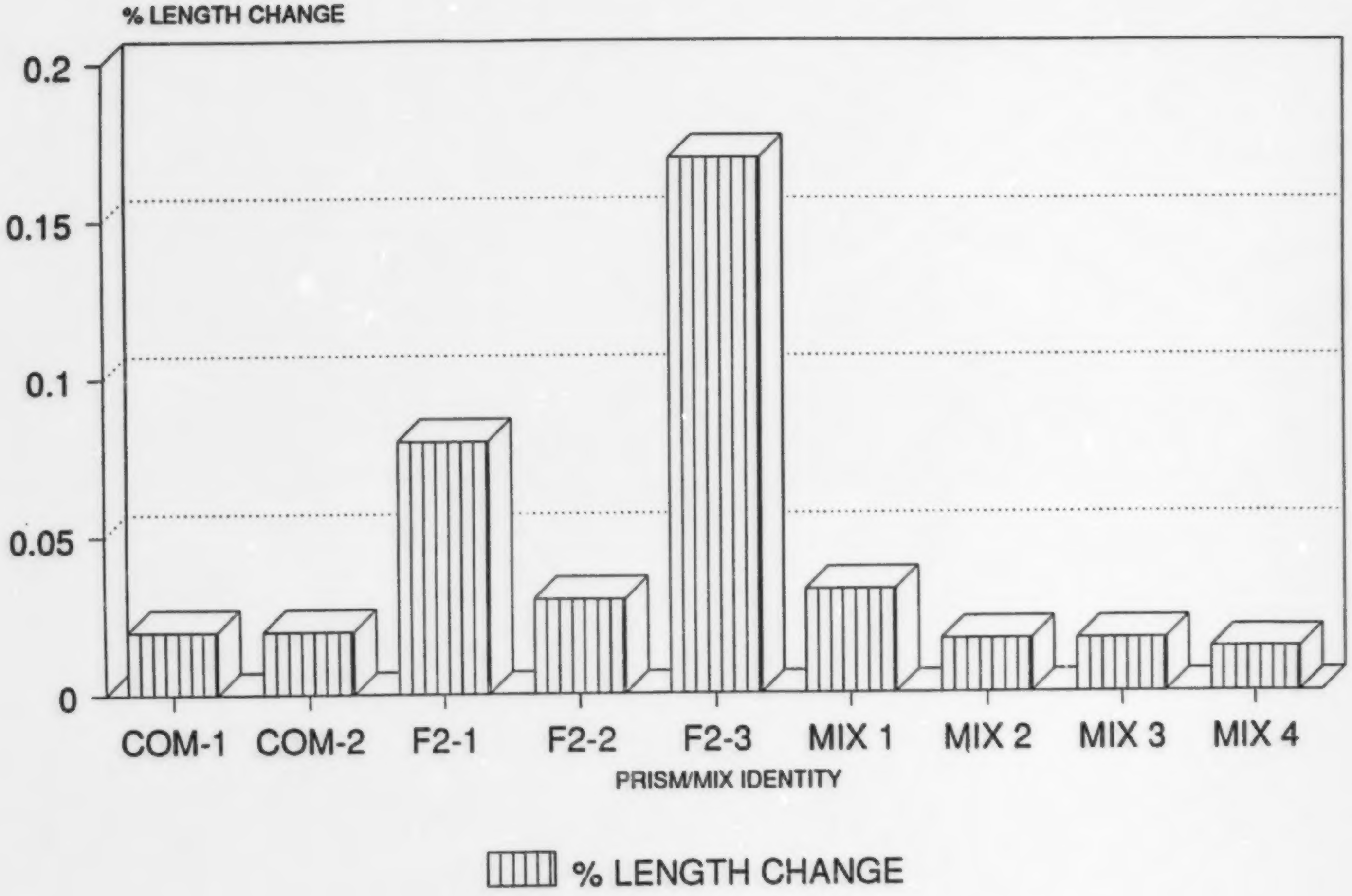
FIGURE 7. COMPARISON OF DATA FOR INORBOND PRISMS

FIGURE 8. % WEIGHT CHANGE
AFTER 300 CYCLES



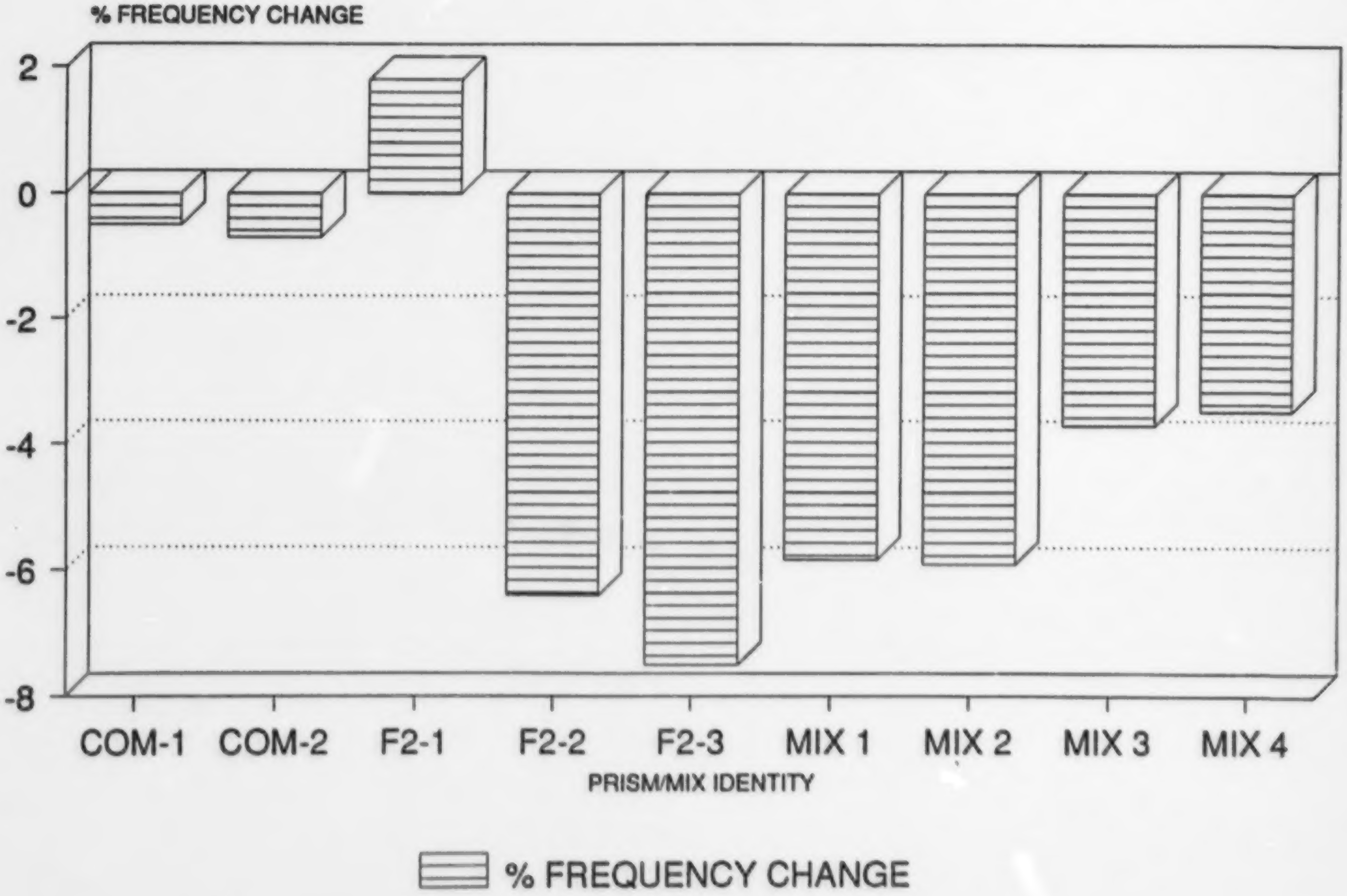
MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 9. % LENGTH CHANGE
AFTER 300 CYCLES



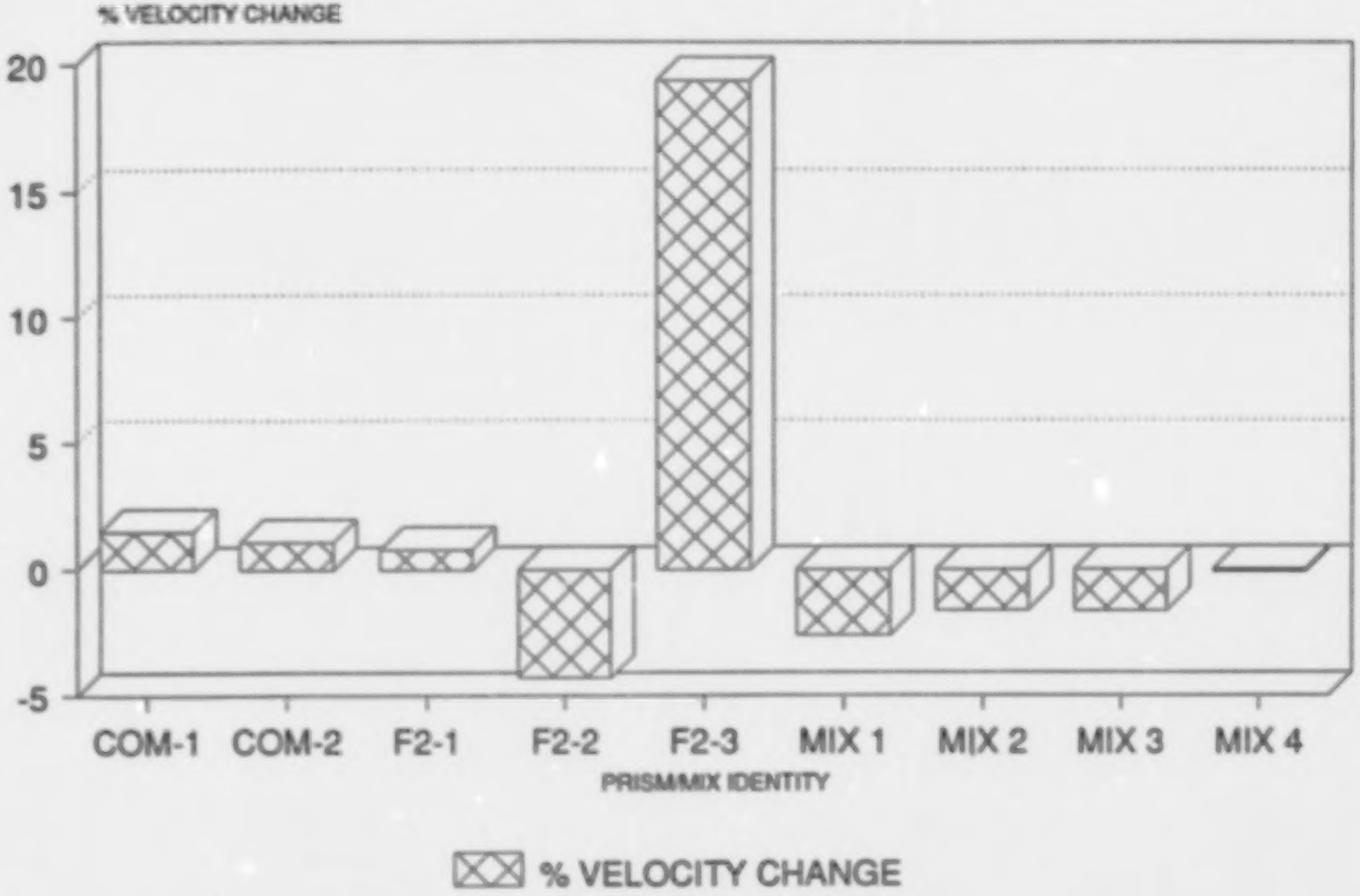
MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 10. % FREQUENCY CHANGE
AFTER 300 CYCLES



MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 11. % VELOCITY CHANGE
AFTER 300 CYCLES



MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

obtained 48 hours after shotcreting support the fast preliminary cure times noted during the program and suggest that the material may have additional applications in areas requiring minimal service interruptions.

6.1 COST ANALYSIS

Assuming that INORBOND is utilised as a shotcrete product to cap the outcroppings of pyritic slate at Halifax International Airport, the following analysis is designed to examine the costs associated with a large-scale rehabilitation to complete the project.

6.1.1 ASSUMPTIONS

i) Inorganic Binders: IB700 (solid), IB7822 (liquid)
ii) Aggregate: Nominal -6mm pea gravel and sand
iii) Application: Modified Shotcrete feed
iv) Mean Thickness: 0.10 metres
v) $IB_{(s)}$:Aggregate Ratio: 1:4
v) Final Product Delivery Specifications: Pre-mixed solid binder and aggregate shipped in supersacks with a 0.63 m^3 capacity. Product supply is F.O.B. Milton, Ontario, Canada. Liquid supply in drums or pails as necessary.

6.1.2 ANALYSIS

A. BINDER SUPPLY COSTS (ALL COSTS PER M^3)

MATERIAL	QUANTITY	COST
Inorbond 700	0.20 m^3	$100.00
Inorbond 7822	0.10 m^3	$128.00
Nominal -6 mm Aggregate	0.80 m^3	$ 32.00
Blending	1.00 m^3	$ 50.00
Packaging Solids	1.00 m^3	$ 56.00
Packaging Liquids	0.10 m^3	$ 25.00
TOTAL PRODUCT SUPPLY		$391.00

At a mean application thickness of 0.10 metres, the quantity of material detailed above would be sufficient to cover 10 m^2 of outcrop area. This cost translates to a cost per m^2 of $39.10. On a per ft^2 basis, the cost is $3.63.

B. CAPITAL EQUIPMENT REQUIREMENTS

Specific capital and consumable equipment requirements for the completion of the project include those items required for efficient application of the shotcrete materials. Experiences with shotcreting equipment in Phase 2 of the program outlined deficiencies in delivery of materials that are attributed to somewhat obsolete equipment.

ITEM	QUANTITY	UNIT COST	TOTAL COST
R-1 Shotcrete Machine	1	$15,000.00	$15,000.00
Vortex Nozzle	2	$ 200.00	$ 400.00
Radial Liquid Feed	2	$ 500.00	$ 1,000.00
Sandpiper Pump	1	$ 1,000.00	$ 1,000.00
Nozzle Inserts	10	$ 25.00	$ 250.00
0.25 X 10 m Piping	3	$ 100.00	$ 300.00
TOTAL SPECIAL CAPITAL EQUIPMENT COSTS			$17,950.00

The unit application cost of this equipment (for amortization purposes) will decrease as area of coverage is increased.

7.0 REFERENCES

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Results of freeze-thaw testing of prisms submitted to CANMET, fax communication, September 7, 1990. 9 pages.

D. Comrie Consulting Ltd., 1988:

Report on Field Work - Hope Brook Drainage Ditch. DCCL Internal Report, July 1988. 6 pages, and plates, appendices.

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APPENDIX 1. SUPPLY AND SERVICES CANADA CONTRACT

Supply and Services Canada   Approvisionnements et Services Canada

Supply and Services Canada
Science Branch
11C1 Phase III
Place du Portage
Hull, Quebec   K1A 0S5

CONTRACT - CONTRAT

You are requested to sell to Her Majesty the Queen in right of Canada, in accordance with the terms and conditions set out herein, referred to herein or attached hereto, the services listed herein and on any attached sheets at the price or prices set out therefor.

Nous vous demandons de vendre à Sa Majesté la Reine du chef du Canada, aux conditions énoncées ou incluses par référence dans les présentes et aux annexes ci-jointes, les services énumérés dans les présentes et sur toute feuille ci-annexée, au(x) prix indiqué(s).

TITLE

TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

The vendor hereby accepts this contract - Le fournisseur accepte le présent contrat

Name, title of person authorized to sign (type or print)
Nom et titre du signataire autorisé (caractère d'imprimerie)   Signature   Date

DELIVERY DATE:

May 15, 1989

▲

Return signed copy forthwith - Prière de retourner une copie dûment signée immédiatement

D. COMRIE CONSULTANTS LTD.   @42K19
120 TRADERS BLVD. EAST
SUITE 209
MISSISSAUGA, ONTARIO
L4Z 2H7   TEL: (416) 890-6500
ATTN: D. COMRIE

Page 1 of/de 16

SSC file No. - N° de référence d'ASC
039SQ.23440-8-9171

Date of Contract - Date du contrat
22 Dec/déc 1988

Contract No. - N° du contrat
23440-8-9171/01-SQ

Requisition No. - N° de la demande

Order office Bureau demandeur	Yr An	Serial No. N° de série
23440	8	9171

Financial Code(s) - Code(s) financier(s)
234-131-000000-303701-0433

Duty - Droits
Included
Compris

F.O.B. - F.A.B.
Destination

Federal Sales Tax - Taxe de vente fédérale
Included
Compris

Destination
DEPT.ENERGY, MINES & RESOURCES
CANMET - MSL DIVISION
555 BOOTH STREET
OTTAWA, ONT.   K1A 0G1
ATTN: MALHOTRA V.M.

Invoices - original and two copies are to be made out and sent to:
Factures - remplir et envoyer l'original et deux copies à:
DEPT.ENERGY, MINES & RESOURCES
CANMET - CONTRACTS OFFICE
555 BOOTH STREET
OTTAWA, ONT.   K1A 0G1
ATTN: S. RISTOW

Address enquiries to: - Adresser toute demande de renseignements à:
D. Lamoureux

Area code Code régional	Telephone No. N° de téléphone	Extension Poste	Telex No. N° de télex
819	956-1342		053-3703

Total est. cost - Coût total est.
$39,564.00

For the Minister - Pour le Ministre
McLenaud

Canada

CONTINUATION - SUITE

Contract No. - N° de contrat: 23440-8-9171/01-SQ

SSC file No. - N° de référence d'ASC: 039SQ.23440-8-9171

TITLE

TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

STATEMENT OF WORK

The Contractor shall carry out the work in accordance with the Statement of Work attached hereto as Appendix "A" and forming part of this contract.

The work will be performed in accordance with the methodology of the contractor's technical proposal entitled, "To Develop Geopolymer Formulations and to Determine Their Mechanical and Durability Properties for Capping of Pyritic Slate Outcrops at Halifax Airport" dated December 15, 1988.

PRIORITY OF DOCUMENTS

The documents listed below form part of and are incorporated into this Contract. If there is a discrepancy between the wording of one document from the wording of any other document which appears on the list, the wording of the document which first appears on the list shall prevail over the wording of any document which subsequently appears on the list:

1. these articles of agreement
2. Statement of Work, Appendix "A"
3. General Conditions Research and Development DSS 9224
4. Basis of Payment, Appendix "B"
5. Contract Plan and Report Form, App. "C"
6. Claim for Progress Payment Form DSS 1111
7. Disclosure Certification, Appendix "F"
8. Cost Submission, Appendix "E"
9. Invoicing Instructions, Appendix "D"
10. Title Page, Appendix "G"
11. Contractor's proposal identified on page 1

MEETINGS

Technical review meetings are to be held if and when considered necessary by the Scientific Authority, at a time and place specified by him.

CONTRACT PLAN AND REPORT FORM

The Contract Plan and Report Form (DSS 9143-3) completed and attached herewith as Appendix "C" forms part of the contract. This form, completed in accordance with the instructions provided in DSS 9143 and 9143-2, must accompany each claim for payment. Receipt and acceptance of the form by the Science Branch Contracting Officer will be a condition of payment for such claims. The Contract Plan and Report Form will provide the basis for measuring the progress of the work and the Contractor's performance under this contract.

MONTHLY PROGRESS REPORTS

You shall prepare and submit progress reports as specified in the "Deliverables" clause.

Each progress report shall be in three (3) parts:

Part 1: The following three questions MUST be answered:

1. Is the project on schedule?
2. Is the project on budget?
3. Is the project free of any areas of concern on which Crown assistance or guidance may be required?

Each negative response must be supported with an explanation.

Part 2: A narrative report, brief, yet sufficiently detailed to enable the Scientific Authority to evaluate the progress of the work, containing as a minimum:

1. A description of the progress of each task and of the work as a whole during the period of the report. Sufficient sketches, diagrams, photographs, etc., shall be included, as necessary to describe the progress accomplished.

2. An explanation of any variation from the plan of work.

3. A description of trips or conferences connected with the contract during the period of the report.

Part 3: The Contract Plan and Report Form, DSS 9143-3, showing the following:

1. actual and forecast expenditure on a monthly basis for the period of work being covered. (Expenditures are to be outlined by month and by task.)

2. progress of the work against your original Contract Plan (instructions for showing the above on the Contract Plan and Report Form attached hereto).

DRAFT AND FINAL REPORT

A copy of the Final Report, in a draft form, as close as reasonably possible to the Final Report itself, is to be submitted for review and comments by the Scientific Authority. Implementation of modifications and editorial changes requested by the Scientific Authority will normally result in the Final Report.

FINAL REPORT

The Final Report must be a comprehensive report on all facets of the work and must include sufficient drawings, sketches, photographs and discussion of problems and successes associated with the work to facilitate a full and accurate evaluation of the work by the Scientific Authority. The report will be prepared in accordance with good engineering practices and will include, as a minimum, the following: title page, list of contents, summary introduction, technical discussion, conclusions and supporting graphs, tables and figures, as applicable.

CONTINUATION - SUITE

Contract No. - N° du contrat: 23440-8-9171/01-SQ
SSC file No. - N° de référence d'ASC: 039SQ.23440-8-9171

The Final Report must contain an executive summary in both English and French. The Final Report will also contain a Title Page. The Title Page is attached as Appendix "F" to this Contract.

DELIVERABLES

Deliverable Item	Delivery Date	Scientific Authority	Science Branch Contracting Officer
Claim	Monthly		Original + 4
Progress Report	Monthly	1	1
Draft Report	May 1, 1989	1	Transmittal Advice
Final Report	May 15, 1989	Orig. + 6	" "
Holdback Claim	" "		Orig. + 4
Disclosure Cert.	" "	1	1
Cost Submission	" "		1

SCIENCE BRANCH CONTRACTING OFFICER

Mrs. Diane Lamoureux
Senior Purchasing Assistant
Science and Professional Services Directorate
Department of Supply and Services Canada
Place du Portage, Phase III, 11C1
11 Laurier Street
Hull, Quebec
K1A 0S5

TELEPHONE: (819) 956-1342
FAX: (819) 997-2229
TELEX: 053-3703

The Science Branch Contracting Officer is responsible for the management of this Contract and any changes to the contract must be authorized by a formal contract amendment issued by that Officer. The Contractor is not to perform work in excess of or outside the scope of this contract based on verbal or written requests or instructions from any government personnel other than the aforementioned officer.

SCIENTIFIC AUTHORITY

Mr. V.M. Malhotra
Energy, Mines and Resources
CANMET, MSL Division
555 Booth Street
Ottawa, Ontario
K1A 0G1

TELEPHONE: (613) 996-5449

The Scientific Authority is reponsible for all matters concerning the scientific and technological content of the work under this contract. Any proposed changes to the scope of the work are to be discussed with the Scientific Authority, but any resultant changes can only be authorized by a contract amendment issued by the Science Branch Contracting Officer.

BASIS OF PAYMENT

The Contractor will be paid its costs reasonably and properly incurred in the performance of the work, in accordance with Appendix "B" attached hereto and forming part of this Contract.

METHOD OF PAYMENT

Monthly progress payments will be made up to 90% of the amounts reasonably and properly incurred in accordance with the Basis of Payment, provided:

(a) the Contractor submits a fully completed claim for progress payment on form DSS 1111, detailed in accordance with the items of the Basis of Payment and showing applicable holdback;

(b) all of the certificates appearing on the said form are signed by the respective persons indicated thereon or their delegate; and

(c) each claim is supported by two full sets of documentation (receipts, invoices, etc.) to support all charges made against the contract, to the satisfaction of the Science Branch Contracting Officer;

(d) a satisfactory progress report including the updated Contract Plan and Report Form is received and accepted.

Claims shall be routed in accordance with the invoicing instructions in Appendix "D" of this contract.

The holdback should be claimed separately on Form DSS 1111 in the same manner described above and will be paid upon:

(e) receipt and acceptance of all deliverables;

(f) receipt of the Contractor's final claim and cost submission;

(g) receipt of a disclosure certification (see Intellectual and Industrial Property clause).

Payment by Her Majesty to the Contractor for the work shall be made:

(h) in the case of a progress payment other than the final payment, within thirty (30) days following the date of receipt of a duly completed progress claim, form DSS 1111;

(i) in the case of a final payment, within thirty (30) days following the date of receipt of a duly completed final progress claim, form DSS 1111, or within thirty (30) days following the date on which the work is completed, whichever date is the later;

(j) if Her Majesty has any objection to the form of the progress claim, within fifteen (15) days of its receipt, She shall notify the Contractor of the nature of the objection. "Form of the progress claim" means a claim which contains or is accompanied by such substantiating documentation as Her Majesty requires. Failure by Her Majesty to act within 15 days will only result in the date specified in paragraphs (a) and (b) above to apply for the sole purpose of calculating interest on overdue accounts.

INTEREST ON OVERDUE ACCOUNTS

(a) (i) In this Article an amount is "due and payable" when it is due and payable by Her Majesty to the Contractor according to the terms of the contract.

(ii) For the purposes of this Article, an amount is overdue when it is unpaid on the first day following the day upon which it is due and payable.

(iii) In this Article "date of payment" means the day prior to the date of the negotiable instrument drawn by the Receiver General for Canada and given for payment of an amount due and payable.

(iv) In this Article "Bank Rate" means the discount rate of interest set by the Bank of Canada.

(b) (i) Her Majesty shall be liable to pay, without demand from the Contractor, simple interest at the Bank Rate plus 1 1/4 per centum on any amount which is overdue from the day such amount became overdue until the day prior to the date of payment, inclusively; interest will not be payable nor paid unless the amount has been outstanding (unpaid) for more than 15 days following the due date. Interest will not be payable on overdue advance payments.

(ii) The Bank Rate shall be that prevailing at the opening of business on the date of payment.

(c) Interest shall only be paid when Her Majesty is responsible for the delay in paying the Contractor. In the event Her Majesty is not responsible for the delay in paying the Contractor, no interest shall be paid.

CONDITIONS PRECEDENT TO PAYMENT

No payment shall be made to the Contractor unless or until:

a) invoices, inspection notes and all other documents prescribed from time to time by the Minister or inspector are submitted in accordance with the terms of the contract or instructions of the Minister;

b) with respect to all materials, parts, work in process or finished work, the cost of which has been paid by the Contractor and in respect of which payment is being made by the Minister, the Contractor, if required to do so, establishes to the satisfaction of the Minister that the materials, parts, work in process or finished work are free from all claims, liens, attachments, charges or encumbrances;

c) with respect to all materials, parts, work in process or finished work, the costs of which have accrued in the accounts of the Contractor as a liability to be discharged in the normal course of business and in respect of which materials, parts, work in process or finished work payment is being made by the Minister, the Contractor, if required to do so, establishes to the satisfaction of the Minister that it is not, in the ordinary course of business, delinquent in discharging its accrued liabilities arising from the performance of the contract and that the payment to be made by the Minister shall be used only for the purpose of discharging such liability and that upon such discharge the materials, parts, work in process or finished work shall be free from all claims, liens, charges or encumbrances; and

d) in the case of payment in respect of finished work, such finished work has been inspected and accepted in accordance with the terms of this Contract.

PROVINCIAL AD VALOREM

The following clause replaces Item 1 under B. Conditions on the reverse side of page 1:

Excluding the exceptions noted below, the Contractor shall not invoice or collect any ad valorem sales tax levied by the province in which the goods or taxable services are delivered to federal government departments and agencies under authority of the following provincial sales tax licences:

Newfoundland	32243-0-09
Prince Edward Island	OP-10000-250
Nova Scotia	U84-00-03172-3
New Brunswick	P87-60-01648
Quebec	Q-398-SS-3921-1-P
Ontario	11708174G
Manitoba	390516-0
British Columbia	005521

Exceptions

(a) Petroleum products subject to provincial gasoline and motor fuel taxes
(b) Tobacco products
(c) Prepared meals and transient living accommodations
(d) Broadcast advertising services (Quebec/Newfoundland) and all other advertising in Newfoundland
(e) Amusement and/or entertainment taxes

In Alberta and Saskatchewan, provincial retail sales taxes do not apply to goods or taxable services delivered to the federal government under this contract.

THE CONTRACTOR IS NOT RELIEVED OF ANY OBLIGATION TO PAY PROVINCIAL SALES TAXES ON GOODS OR TAXABLE SERVICES USED OR CONSUMED IN THE PERFORMANCE OF THIS CONTRACT, INCLUDING MATERIALS INCORPORATED IN REAL PROPERTY.

LIMITATION OF EXPENDITURE

Her Majesty's liability to the Contractor shall not exceed $35,564.00 inclusive of Federal Sales Tax, where exigible and paid by the Contractor, unless otherwise authorized in writing by the Science Branch Contracting Officer. The Contractor shall not be obliged to perform any work or provide any service that would cause the total liability of Her Majesty to exceed the said sum, unless an increase is so authorized. The Contractor shall notify this Department as to the adequacy of this sum when it is 75% committed. If the notification refers to inadequate funds, then the Contractor shall, at the same time, provide a new estimate of the total cost of the work. Notwithstanding the aforegoing, the Contractotr shall notify this Department and provide a new estimate of cost if at any time the Contractor considers the funds provided are inadequate for the completion of the work. The giving of such notification and estimates shall not increase her Majesty's liability over the Limitation of Expenditure listed above.

The Contractor shall not adopt any change or changes in the work that would cause an increase in the cost of the work, until the Contractor receives written authorization from the Science Branch Contracting Officer. Costs incurred without such authorization shall not be reimbursed by Her Majesty.

COST SUBMISSION

Upon completion of the contract the Contractor shall prepare and submit a Cost Submission to the Science Branch Contracting Officer designated herein. The Cost Submission shall be a statement of the costs incurred by the Contractor in accordance with the Basis of Payment, for the work performed under the terms of the contract.

The Cost Submission shall be signed and certified by the Contractor's Senior financial officer and shall contain a breakdown of each element of cost.

Supporting information for each element of cost shall be available and shall be in sufficient detail that an in-depth audit can be carried out (see Appendix "E").

DISCRETIONARY AUDIT

The following are subject to Government audit before or after payment is made:

(a) Amounts claimed under the terms and conditions of the contract as computed in accordance with the Basis of Payment including time charged, and salaries paid for labour charges based on salaries times a firm negotiated multiplier.

(b) The accuracy of the Contractor's time recording system.

(c) The estimated amount of profit in any firm priced element, firm time rate, firm overhead rate, or firm salary multiplier, for which the Contractor has provided the appropriate certification. The purpose of such audit would be to determine whether the aggregate of actual profit earned by the Contractor on a series of negotiated contracts containing one or more of the aforementioned prices, time rates or multipliers, and received during a particular period selected, is fair and reasonable based on the estimated amount of profit included in earlier certifications.

(d) Any firm priced element, firm time rate, firm overhead rate, or firm salary multiplier for which the Contractor has provided a "most favoured customer" certification. The purpose of such audit would be to determine whether the Contractor has charged anyone else, including the Contractors most favoured customer, lower prices, rates or multipliers, for like quality and quantity of goods or services.

Any payments made pending completion of the audit shall be regarded as interim payments only and shall be adjusted to the extent necessary to reflect the results of the audit. If there has been any overpayment it shall be promptly refunded to the Crown.

INTELLECTUAL AND INDUSTRIAL PROPERTY

Final payment under the contract will be made only after receipt by the Science Branch Contracting Officer and the Scientific Authority of a certification made by an officer of the Contractor, stating that all applicable disclosures were submitted or that there were no disclosures to submit. A copy of these certifications are attached as Appendix "F".

CONFLICT OF INTEREST

It is a term of this Contract that no former public office holder who is not in compliance with the post-employment provisions of the Conflict of Interest and Post-Employment Code for Public Office Holders shall derive a direct benefit from this Contract.

SOUTH AFRICAN CONDITION

(1) Subject to subsection (2), the Contractor shall ensure that, to its knowledge, the goods and services to be provided pursuant to this Contract are neither of South African origin nor obtained from a company that is majority-owned (51 percent of the voting rights) by South African interests.

(2) Where the Contractor is aware that goods or services of South African origin or obtained from companies that are majority-owned by South African interests are to be supplied in connection with this Contract, the Contractor shall in its response identify the items involved, the estimated total value of the goods and services, and the justification for their use.

(3) Following a review of the Contractor's justification, the Minister may accept or reject the justification, at the sole discretion of the Minister.

(4) Where the Minister rejects the Contractor's justification referred to in subsection (3), the Minister may terminate the contract in accordance with subsection (5).

(5) The Contractor agrees that the Minister relies upon subsections (1) and (2) to enter into this Contract and any breach of subsection (1) or (2) shall entitle the Minister to terminate this contract for default and to recover from the Contractor damages, including reprocurement costs arising out of such termination.

(6) The Contractor agrees to bind each first-tier Canadian-based subcontractor by the terms of this clause.

EXPIRY DATE

Notwithstanding the delivery date of the Final Report, this Contract will remain in effect until 90 days after the specified delivery date of the Final Report. During this 90 day time period, miscellaneous activity relating to contract close-out will occur.

Notwithstanding the above, no costs are to be incurred after the delivery date stipulated without written approval of the Science Branch Contracting Officer.

GENERAL CONDITIONS

In lieu of General Conditions DSS 9329 referred to in the reverse side of Page 1, the terms and conditions of General Conditions Research and Development DSS 9224 (8/84) as modified hereunder, shall apply to and form part of this Contract.

Modifications:

(i) Conduct of the Work: Part 2, Article 7 of the Terms and Conditions DSS 9224 is hereby supplemented by adding the following subsection:

(5) The Contractor shall not stop or suspend work pending the settlement or determination of any differences arising under the contract, unless so instructed by the Minister.

(ii) Subcontracts: Article 11 of the Terms and Conditions DSS 9224 is hereby supplemented by adding the following sentence to subsection 1:

For work requiring consent, should the Contractor propose to solicit bids from other than Canadian sources, the Contractor shall obtain the consent, in writing, of the Minister prior to solicitation.

(iii) Paragraph (b) of subsection 2 of Article 21 of Terms and Conditions DSS 9224 is deleted in its entirety and the following is substituted therefor:

b) the Work or any portion of the Work is terminated, the Contractor shall be paid for all finished deliverables delivered and accepted and for all materials or work-in-process delivered and acceptable to Her Majesty, the Cost to the Contractor in accordance with the terms of the contract plus the proportional part of any fee applicable thereto. The Contractor shall also be entitled to be reimbursed its costs which are incidental to the cancellation of obligations incurred by the Contractor pursuant to the termination notice, the cost of preparing the necessary accounts and statements with respect to the Work performed to the effective date of such termination and commitments made by the Contractor with respect to the terminated portion of the Work, wages which the Contractor is obliged under any laws or regulations for the time being in force, to pay employees whose services are no longer required by reason of such termination, the costs of and incidental to the taking of any inventory of materials, components, work-in-process and finished work on hand at the effective date of the termination and other costs and expenses of and incidental to the termination in whole or in part, of operations under the contract; provided always that payment and reimbursement under the provisions of the subsection shall be made only to the extent that is established to the satisfaction of the Minister that the said costs and expenses were actually incurred by the Contractor and that the same are reasonable and are properly attributable to the termination of the Work or the part thereof so terminated.

c) In no event shall the aggregate of the price paid to date and the amounts payable pursuant to this Article, exceed the total Contract Price.

d) The Contractor shall have no claim for damages, compensation, loss of profit, allowance or otherwise by reason of or directly or indirectly arising out of any action taken, or notice given by the Minister under or pursuant to the provisions of this Article except as and to the extent expressly provided."

APPENDIX "A"

14SQ.23440-8-9171

STATEMENT OF WORK

The contractor will develop geopolymers formulations for capping pyritic slate outcrops at Halifax International Airport. The formulations will be developed with a view of optimising the use of geopolymers and other mineral admixtures such as fly ash slag and silica fume. Data on mechanical properties such as compression, flexural and modulus of elasticity will be developed. Additional test specimens will be cast for determining the freezing and thawing resistance permeability and coefficient of thermal expansion of geopolymer systems, large panels will be shotcreted to test the applicability of the geopolymers using a shotcrete gun. The panels will be cored to determine the mechanical properties of the material. Data obtained in the above investigation will be analyzed as to determine the feasibility of using the geopolymer technology for capping the pyritic slate outcrops and cost estimates of doing such a job will be given.

APPENDIX "B"

39SQ.23440-8-9171

BASIS OF PAYMENT

LABOUR

At firm hourly rates inclusive of overhead and profit

	Estimated Days	Firm Hourly Rates
Senior Project Leader	48	$88.00
Technician 1	104	$59.00
Technician 2	104	$43.00
Secretary	8	$31.00

Total Estimated Cost of Labour:	$15,080.00

EQUIPMENT

At laid down cost without mark-up	$ 1,500.00

MATERIAL, SUPPLIES AND COMPONENTS

At laid down cost without mark-up	$ 200.00

SUBCONTRACT

At laid down cost without mark-up	$20,700.00

TRAVEL AND LIVING

At actual cost not to exceed Travel and Living Guidelines attached on the following page 2	$ 1,684.00

OTHER DIRECT CHARGES

At laid down cost without mark-up	$ 400.00

TOTAL CONTRACT PRICE TO A LIMITATION OF EXPENDITURE:	$39,564.00

TRAVEL AND LIVING GUIDELINES

MEALS

	ALL PROVINCES	YUKON AND N.W.T.	U.S.A.
Breakfast	$ 6.40	$ 8.20	$ 6.90
Lunch	$ 8.50	$10.10	$ 9.00
Dinner	$18.10	$21.20	$19.10
Total Daily Meal Allowances	$33.00	$39.50	$35.00

INCIDENTAL EXPENSES

You may claim up to $6.00 per full day (24 hours) in travel status when commercial accommodation is used and up to $4.00 when private accommodation is used.

SPECIAL TRAVEL SITUATIONS

When unusually high costs are incurred, such as during field reseach in the far north, actual expenses for incidentals and meals will be reimbursed, based on proof of payment, to the extent that the Minister considers the expenses claimed are reasonable and justifiable in the circumstances.

ACCOMMODATION

Single occupancy commercial accommodation of reasonable quality and comfortably equipped. LUXURY ACCOMMODATION IS NOT PERMITTED.

For private accommodation provided by friends or relatives: $13.50 (CDN) per night in Canada, and $13.50 (U.S.) per night in the U.S.A.

TRANSPORTATION

Intercity:

Intercity (air/rail/bus) transportation costs: use the most practical, economy class public transportation.

Private vehicle mileage reimbursement shall not exceed the most practical economy class, public transit fare. Use of private vehicles not authorized for travel destination in excess of 200 miles/320 km.

.../3

Mileage rates to a maximum of 4,000 miles or 6,500 km

N.S., N.B., P.E.I. & B.C.	Man., Sask. & Alta.	N.W.T. Yukon	Nfld.	Quebec	Ontario
46.5 /mile	44.5 /mile	56.5 /mile	49.0 /mile	47.0 /mile	47.0 /mile
29.0 /km	27.5 /km	35.0 /mile	30.5 /km	29.5 /km	30.5 /km

Local

Use public transit (airport buses, etc.) where applicable.

Rent compact economy cars unless the number of passengers or load justifies a larger vehicle. (Personal accident coverage is not allowable).

RECEIPTS AND VOUCHERS

A statement indicating the names of travellers, places visited and when, length of visits and purpose of travel, must be submitted with each claim for travel and living expenses.

Receipts and vouchers for accommodation and transportation may be required to be submitted with claim. No receipt or voucher is required for private accommodation.

ENTERTAINMENT IS NOT AN ALLOWABLE COST

(October 1, 1988)

Supply and Services Canada   Approvisionnements et Services Canada

DSS-MAS 9143-3 (4/81)

CONTRACT PLAN AND REPORT FORM — FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE — TITRE DU CONTRAT

CONTRACTOR — ENTREPRENEUR

FILE NO. — Nº DU DOSSIER

SERIAL NO. — Nº DE SÉRIE

TASK DESCRIPTION DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS — DURÉE DE LA TÂCHE EN MOIS												TASK COST — COÛT DE LA TÂCHE		
	1 JAN	2 FEB	3 MAR	4 APRIL	5 MAY	6	7	8	9	10	11	12	PLANNED PRÉVU À L'ORIGINE	ACTUAL PRÉSENTEMENT	E.T.C. À VENIR
DATA REVIEW	☐												1,560		
MIX DESIGN	☐												11,630		
PHYSICAL TESTING (I)		☐											14,300		
SITE EVALUATION		☐											1,974		
APPLICATION TRIALS		☐											4,220		
PHYSICAL TESTING (II)			☐	☐									5,600		
REPORT (FINAL)				☐									4,820		
PLANNED COST BY MONTH COÛT PRÉVU POUR CHAQUE MOIS													PLAN 44,104	▨	▨
ACT. PRÉSEN. — E.T.C. BY MONTH PRÉVISION POUR CH. MOIS	13,190	20,474	2,800	7,620									▨	ACTUAL COÛTS RÉELS	E.T.C. À VENIR

Appendix "C"

DSS-MAS 9143 (8/81)

CONTRACT PLAN AND REPORT FORM

Instructions to Contractor

This form serves a dual purpose; the first is for planning and estimating the work, and the second is for reporting actual progress against the plan during contract execution.

PROPOSED PLAN

Your work and cost plan must be prepared on this "Contract Plan and Report Form" DSS-MAS 9143-3 and must be submitted as part of your proposal. The plan shall demonstrate how you propose to execute the contract by subdividing the work into tasks and providing for each task an estimate of the cost and a schedule for completion. An example of a completed form is attached, (page I).

Use additional pages if the number of tasks exceed 15, or if the contract duration will exceed 12 months. For high value contracts in excess of $1M you are required to subdivide the work into major tasks which in turn are to be subdivided into minor tasks, e.g. a system is divided into subsystems which in turn are divided into subtasks, such as subsystem components.

You will be required to revise your plan to reflect the results of the contract negotiation. The revised plan will form part of contract.

REPORTING PROGRESS

Following contract award, monthly progress reports which record actual start dates and projected completion dates by task, actual cost by task, actual cost by month, Estimate to Complete (E.T.C.) by task and E.T.C. by month are to be prepared and submitted in accordance with the attached example, (page II), unless otherwise noted in the contract.

NOTE: The contract file number, serial number and the actual months duration are to be entered in the appropriate blocks of the first and subsequent reports. The report period is to be indicated by drawing a solid vertical line at the end of the applicable month. Your progress report must be completed to the satisfaction of the Science Procurement Manager before progress claims will be processed for payment.

The following points concerning the attached example should be noted:

1) Reports actual progress to the end of August.
2) Actuals by month are recorded on the bottom line at the left of the date line and Estimate to Complete by month to the right of the date line.
3) MECHANICAL SUBSYSTEM Material Procurement started one month late, is projected to be completed on time, has cost $4M and the Estimate to Complete is $1M. Total subtask is expected to cost $5M.
4) MECHANICAL SUBSYSTEM Assembly is expected to start one month late and to be completed one month late. The expected late completions are to be highlighted using broken lines.
5) ELECTRICAL SUBSYSTEM Assembly started one month early and is expected to be completed one month early.
6) DISPLAY CONTROL SUBSYSTEM Procurement is 50% complete in terms of cost. The estimated completion date has slipped 2 months.
7) SYSTEM INTEGRATION AND SYSTEM TEST are both expected to start one month late reflecting the one month delay in MECHANICAL SUBSYSTEM Fabrication and Assembly.
8) As of the end of August, the total contract cost is expected to be $26M ($12.7M Actual plus $13.3M E.T.C.) or to equal the planned cost of $26M. The contract is expected to be completed one month later than planned.

FORMULE DE PROJET DE CONTRAT ET RAPPORT

Instructions aux entrepreneurs

Cette formule a un double but; elle sert premièrement à planifier et estimer le travail, et deuxièmement, à vérifier, tout au long de l'exécution du contrat, si les travaux se déroulent selon le plan.

PLAN PROPOSÉ

Les plans concernant les travaux et les coûts prévus doivent être établis sur la "Formule de projet de contrat et de rapport" DSS-MAS 9143-3 et doivent être présentés comme faisant partie de votre proposition. Le plan doit faire état de la façon dont vous prévoyez mettre le contrat à exécution en divisant le travail en tâches et en donnant, pour chaque tâche, une estimation du coût et un calendrier d'exécution. Ci-joint à la page I un exemple de formule remplie.

Utilisez des pages additionnelles si le nombre de tâches dépasse 15 ou si la durée du contrat est de plus de douze mois. Pour les gros contrats d'une valeur supérieure à $1M, divisez le travail à accomplir en tâches principales que vous subdiviserez par la suite en tâches secondaires. Pensez, par exemple, à un système divisé en sous-systèmes, qui, à leur tour, sont subdivisés en sous-tâches, comme des composants du sous-système.

Vous devrez réviser votre plan pour tenir compte des résultats des négociations; le plan révisé fera partie du contrat.

RAPPORT DE SITUATION

Lorsqu'un contrat est adjugé, il faut remplir un rapport de situation mensuel indiquant la date à laquelle chaque tâche a été entreprise, ainsi que la date prévue d'achèvement de chaque tâche, la somme dépensée tous les mois pour chaque tâche et le coût prévu d'achèvement par tâche et par mois et présenter ce rapport de la façon indiquée à la page II ci-jointe, à moins qu'il n'en soit indiqué autrement dans le contrat.

NOTA: Le numéro de dossier du contrat, le numéro de série et la durée actuelle en mois doivent être inscrits dans les cases correspondantes du premier rapport et des rapports subséquents. La fin de la période visée par le rapport doit être indiquée au moyen d'un trait vertical plein après le mois en question. Le rapport de situation doit être jugé satisfaisant par le directeur de l'approvisionnement scientifique avant que les demandes d'acompte ne soient traitées.

Soulignons les points suivants en ce qui concerne l'exemple annexé:

1) Les progrès, y compris ceux accomplis à la toute fin du mois d'août, figurent sur le rapport.
2) Les coûts réels, par mois, figurent en bas, à gauche du trait vertical plein indiquant la fin de la période visée par le rapport; le coût prévu pour l'exécution complète, en bas, à droite du trait vertical.
3) Ainsi, on voit que l'achat de matériel pour le sous-système mécanique a commencé un mois en retard, qu'on prévoit qu'il sera terminé à la date prévue. Cette tâche a coûté jusqu'ici $4M et on prévoit qu'elle coûtera un autre million d'ici à la fin des travaux. On prévoit donc qu'en tout, cette tâche aura coûté $5M.
4) L'assemblage du sous-système mécanique commencera probablement un mois en retard et se terminera aussi un mois en retard. Il faut mettre en relief les retards prévus au moyen de pointillés.
5) L'assemblage du sous-système électronique a débuté un mois en avance et devrait être terminé un mois en avance.
6) L'achat du sous-système de contrôle de l'affichage est exécuté à 50% en ce qui touche les coûts. La date prévue d'achèvement a toutefois été reportée de deux mois.
7) L'intégration et les vérifications du système devraient commencer deux mois en retard à cause du retard accusé au niveau de la fabrication et de l'assemblage du sous-système mécanique.
8) À la fin du mois d'août, on prévoit que le coût total du contrat sera de $26M ($12.7M déjà engagés et une dépense de $13.3M de prévue), c'est-à-dire qu'il atteindra le coût de $26M. La date d'achèvement a toutefois été reportée d'un mois.

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DSS-MAS [illegible]

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT

CONTRACTOR – ENTREPRENEUR

FILE NO. – Nº DU DOSSIER

SERIAL NO. – Nº DE SÉRIE

TASK DESCRIPTION DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COÛT DE LA TÂCHE		
	1	2	3	4	5	6	7	8	9	10	11	12	[illegible]	[illegible]	E.T.C. [illegible]
													[illegible]	▨	▨
PLANNED COST BY MONTH COÛT PRÉVU POUR CHAQUE MOIS													▨	[illegible]	E.T.C. [illegible]
ACT. [illegible] | E.T.C. BY MONTH PRÉVISION POUR CH. MOIS															

Supply and Services Canada   Approvisionnements et Services Canada

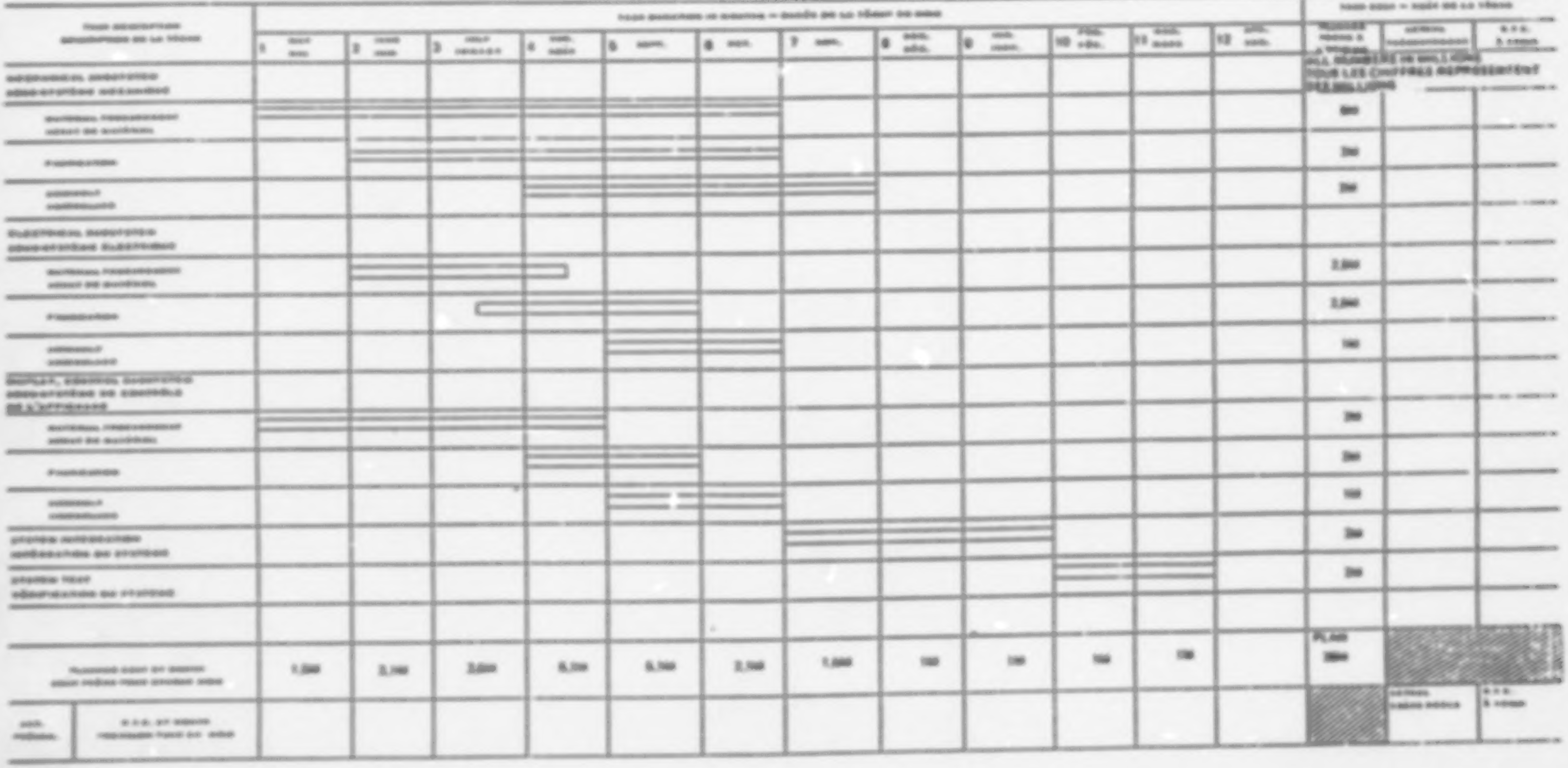
[illegible]

Page [illegible]

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: GIZMO DEVELOPMENT, ENGINEERING MODEL

CONTRACTOR – ENTREPRENEUR: ACME INDUSTRIES LTD.



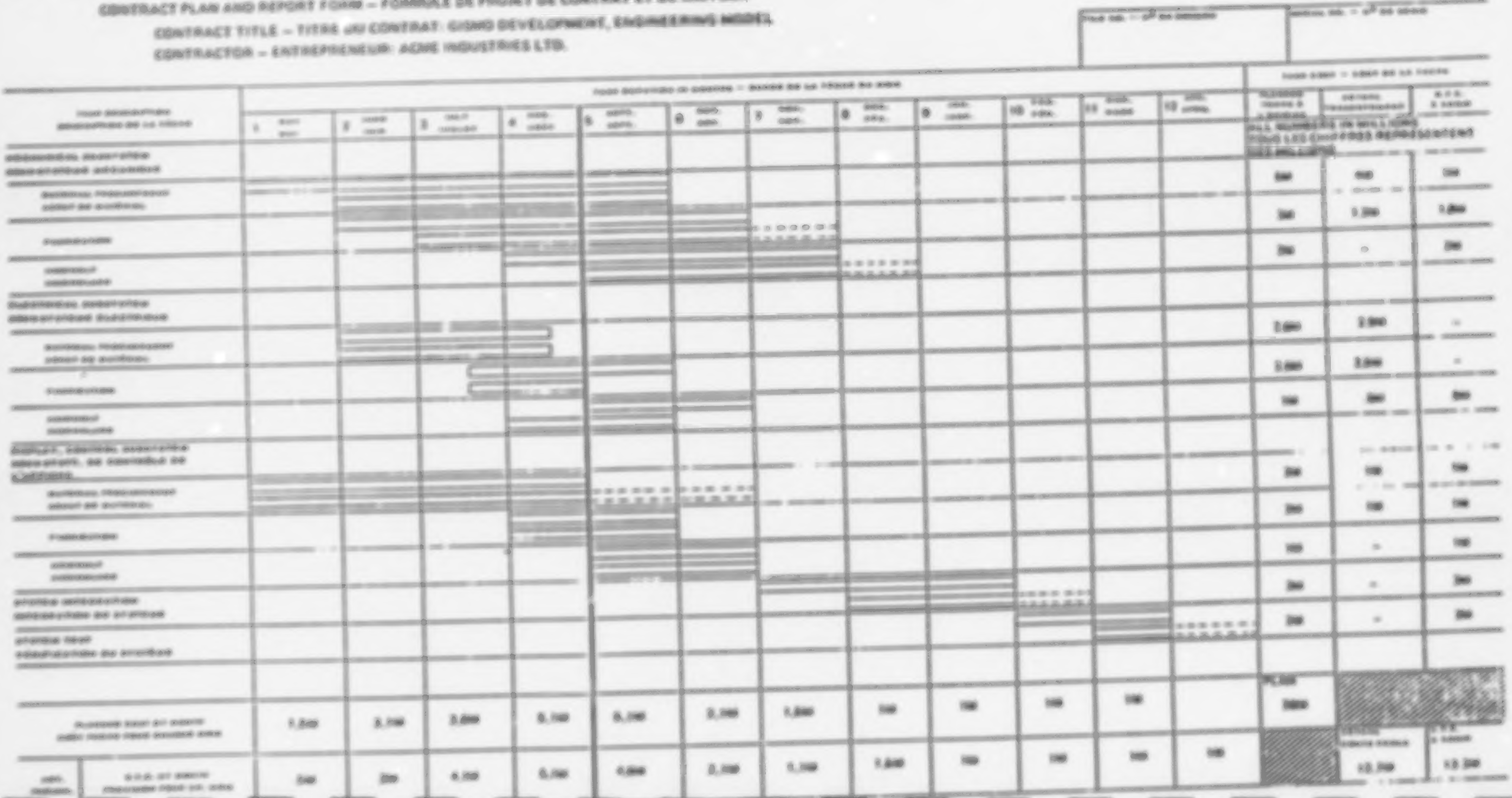
[illegible]	[illegible]												[illegible]		
	1 [illegible]	2 [illegible]	3 [illegible]	4 [illegible]	5 [illegible]	6 [illegible]	7 [illegible]	8 [illegible]	9 [illegible]	10 [illegible]	11 [illegible]	12 [illegible]	[illegible]	[illegible]	[illegible]
[illegible]													ALL NUMBERS [illegible] TOUS LES CHIFFRES REPRÉSENTENT [illegible]		
[illegible]													500		
[illegible]													200		
[illegible]													200		
[illegible]															
[illegible]													2,000		
[illegible]													2,000		
[illegible]													100		
[illegible]															
[illegible]													200		
[illegible]													200		
[illegible]													100		
[illegible]													200		
[illegible]													200		
[illegible]	1,500	2,100	2,000	6,100	6,100	2,100	1,000	100	100	100	100		PLAN [illegible]		
[illegible]														[illegible]	[illegible]

Supply and Services Canada   Approvisionnements et Services Canada

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: GISMO DEVELOPMENT, ENGINEERING MODEL

CONTRACTOR – ENTREPRENEUR: ACME INDUSTRIES LTD.



APPENDIX "D"

PROGRESS PAYMENT ROUTING

FROM: D. COMRIE CONSULTING LTD.

TO: DIANE LAMOUREUX

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

CLAIM NO.:

DSS FILE NO.: 39SQ.23440-8-9171

SERIAL NO.: 23440-8-9171/01-SQ

FINANCIAL CODE: 234-131-000000-303701-0433

The original, four (4) copies of the progress claim DSS 1111 and two (2) copies of supporting documentation are to be forwarded for certification as follows:

ADDRESSEE	INITIALS	DATE SENT TO NEXT ADDRESSEE
(1) Senior Purchasing Assistant Mrs. Diane Lamoureux DSS/Science Branch Place du Portage, Phase III, 11C1 11 Laurier Street Hull, Quebec K1A 0S5		
(2) Scientific Authority Mr. V.M. Malhotra Energy, Mines and Resources CANMET, MSL Division 555 Booth Street Ottawa, Ontario K1A 0G1		
(3) Accounts Office Mrs. Shirley Ristow Energy, Mines and Resources CANMET, Contracts Office Rm 167A, 555 Booth Street Ottawa, Ontario K1A 0G1		

NOTE: SEE "DELIVERABLES" CLAUSE FOR ROUTING OF OTHER DELIVERABLES

APPENDIX "G"

SAMPLE TITLE PAGE

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

FINAL REPORT

BY:

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada.

DSS FILE NO.: 14SQ.23440-8-9171

DSS CONTRACT SERIAL NO.: 23440-8-9171/01-SQ

CANMET PROJECT NO.:

CANMET SCIENTIFIC AUTHORITY:

DATE:

APPENDIX 2. PHASE 1 MIX FORMULATIONS & PHYSICAL TESTING DATA

TABLE 1(a): EFFECT OF DIFFERENT BINDER FORMULATIONS ON PRODUCT CHARACTERISTICS

	SAMPLE NUMBER								
	10-25-1	10-25-2	10-25-3	10-25-4	10-25-5	10-25-6	10-25-7	10-25-8	10-25-9
INORBOND									
TYPE A	32.9%		13.8%	15.1%		26.8%	13.2%	13.5%	34.6%
TYPE B									
TYPE C									
TYPE D									
TYPE E									
Slag									
Silica Fume						11.6%	5.7%	5.8%	
Ca(OH)2	11.6%		4.8%	5.3%		6.0%	2.9%	3.0%	5.5%
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	38.9%	14.5%	16.3%			38.9%		19.5%	18.5%
Caustic 1	16.7%	6.2%	7.0%			16.7%		8.4%	7.9%
Caustic 2									
GP52A				25.6%	21.1%		27.2%		
GP52B		16.6%			16.9%				
Sand		62.6%	58.2%	54.0%	61.9%		51.0%	49.8%	28.5%
Water									5.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

NOTES:
1. Compositions refer to weight percentages
2. Inorbond, IB and GP52 components represent different varieties of geopolymeric binder

	10-25-10	10-28-1	10-28-2	10-28-3	10-28-4	10-28-5	10-28-6	10-28-7	10-28-8
INORBOND									
TYPE A	38.9%	28.9%		22.8%	17.7%	22.2%	17.0%		17.0%
TYPE B								12.9%	
TYPE C									
TYPE D									
TYPE E									
Slag									
Silica Fume									
Ca(OH)2	10.5%				5.0%		4.8%	3.6%	4.8%
CaF2					6.3%			4.5%	
CaO		10.1%		8.0%					
CaSO4							10.2%		
IB DRY ACTIVATOR									
Gypsum									10.2%
IB LIQ. ACTIVATOR	35.4%	42.7%	25.2%	26.9%	25.3%	77.8%	24.3%	18.4%	24.3%
Caustic 1	15.2%	18.2%		11.5%	10.8%		10.4%	7.9%	10.4%
Caustic 2									
GP52A									
GP52B									
Sand			74.8%	30.8%	34.9%		33.4%	52.7%	33.4%
Water									
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	10-28-9	11-3-1	11-4-1	11-4-2	11-7-1	11-7-2	11-7-3	11-7-4	11-7-5
INORBOND									
TYPE A	8.9%	9.3%							
TYPE B									
TYPE C									
TYPE D			24.3%	13.2%	25.0%	23.8%	22.5%	21.3%	20.0%
TYPE E									
Slag		12.5%		13.2%					
Silica Fume									
Ca(OH)2		3.3%				1.3%	2.5%	3.8%	5.0%
CaF2	5.7%		6.7%						
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	12.8%	21.9%	22.5%	17.6%	17.5%	17.5%	17.5%	17.5%	17.5%
Caustic 1	5.5%	9.4%	9.6%	7.6%	7.5%	7.5%	7.5%	7.5%	7.5%
Caustic 2									
GP52A									
GP52B									
Sand	67.2%	43.8%	37.0%	48.5%	50.0%	50.0%	50.0%	50.0%	50.0%
Water									
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-7-6	11-8-1	11-8-2	11-8-3	11-8-4	11-8-5	11-9-1	11-9-2	11-9-3
INORBOND									
TYPE A									
TYPE B									
TYPE C									
TYPE D	33.2%	20.0%	14.5%	11.4%	18.0%	20.0%	13.8%	12.5%	14.7%
TYPE E									
Slag							1.4%	3.1%	5.9%
Silica Fume							3.5%	5.0%	1.5%
Ca(OH)2		5.0%	3.6%	2.9%	4.5%	5.0%			
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	16.9%	17.5%	12.7%	10.0%	11.2%		14.5%	13.2%	15.4%
Caustic 1	7.3%	7.5%	5.4%	4.3%	11.2%		6.2%	5.6%	6.6%
Caustic 2									
GP52A						25.0%			
GP52B									
Sand	42.5%	50.0%	54.3%	57.1%	55.0%	50.0%	60.6%	60.5%	56.0%
Water			9.5%	14.3%					
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-9-4	11-9-5	11-9-6	11-9-7	11-9-8	11-10-1	11-10-2	11-10-3	11-10-4
INORBOND									
TYPE A									
TYPE B									
TYPE C									
TYPE D	6.4%	6.3%	6.3%	4.9%	6.3%	9.1%	6.1%	7.6%	4.3%
TYPE E									
Slag	6.4%	6.3%	6.3%	4.9%	6.3%	9.1%	13.0%	9.1%	9.3%
Silica Fume	6.4%	6.3%	6.3%	4.9%	6.3%	1.5%	0.6%	3.0%	0.4%
Ca(OH)2									
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	13.4%	1.9%		13.7%	9.4%	13.8%	13.8%	13.8%	9.9%
Caustic 1	5.8%	16.9%		5.9%	9.4%	5.9%	5.9%	5.9%	4.3%
Caustic 2									
GP52A			18.8%						
GP52B									
Sand	61.7%	62.5%	62.5%	65.8%	62.5%	60.6%	60.6%	60.6%	67.7%
Water									4.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-10-5	11-10-6	11-11-1	11-11-2	11-15-1	11-15-2	11-15-3	11-25-1	11-25-2
INORBOND									
TYPE A									
TYPE B									
TYPE C									
TYPE D	8.9%	8.3%						5.0%	5.0%
TYPE E			6.0%	6.0%	18.9%	9.0%			
Slag	8.9%	3.3%	13.0%	13.0%				10.8%	10.8%
Silica Fume	0.9%		1.0%	1.0%	1.1%	0.6%		0.8%	0.8%
Ca(OH)2	1.3%	3.3%							
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR					2.2%	1.3%	33.3%		
Gypsum									
IB LIQ. ACTIVATOR	14.0%	10.5%	14.0%	2.0%	15.6%	9.0%		14.5%	14.5%
Caustic 1	6.0%	4.5%		18.0%		3.8%			6.2%
Caustic 2			6.0%		6.7%			6.2%	
GP52A									
GP52B									
Sand	60.0%	60.0%	60.0%	60.0%	55.6%	69.9%	50.0%	62.6%	62.6%
Water		10.0%				6.4%	16.7%		
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-25-3	11-25-4
INORBOND		
TYPE A		
TYPE B		
TYPE C		
TYPE D		5.0%
TYPE E		
Slag		10.8%
Silica Fume		0.8%
Ca(OH)2		
CaF2		
CaO		
CaSO4		
IB DRY ACTIVATOR		
Gypsum		
IB LIQ. ACTIVATOR	14.5%	
Caustic 1	6.2%	
Caustic 2		
GP52A		20.8%
GP52B	16.6%	
Sand	62.6%	62.6%
Water		
TOTAL	100.0%	100.0%

TABLE 1(b): EFFECT OF DIFFERENT BINDER FORMULATIONS ON PRODUCT CHARACTERISTICS

	SAMPLE NUMBER								
	10-25-1	10-25-2	10-25-3	10-25-4	10-25-5	10-25-6	10-25-7	10-25-8	10-25-9
REACTION TIME(min)	15	40	5	5	30	10	23	5	0
SETTING TIME(min)	0	0	15	0	0	0		10	0
COMMENTS:	MIXTURE SET BEFORE SAND ADDED.	SET NEXT DAY. NO CRACKS.	CRACKED WHEN DEMOLDE WILL NOT DISSOLVE IN H2O.	SET NEXT DAY. NO CRACKS. SOFT. HARD NEXT WEEK.	SET NEXT DAY. NO CRACKS.	MIXTURE SET BEFORE SAND ADDED.	SET SLOWLY. CRACKED BADLY.	BADLY CRACKED.	FLASH SET.
EVALUATION									
VISCOSITY-	0	5	1	1	5	0	1	2	0
SET TIME-	0	5	2	2	5	0	1	2	0
CRACKING-	0	5	1	5	5	0	1	0	0
1 DAY HARDNESS-	0	5	2	1	5	0	1	1	0
7 DAY HARDNESS-	0	5	2	5	5	0	0	3	0
SCORE	0	25	8	14	25	0	4	8	0

NOTES:

1. Reaction time: Delay time before adding aggregate
2. Set time: Time to hardening and zero slump.
3. Viscosity: Thickness of mix (qualitative); 5= maximum viscosity
4. Cracking: Qualitative evaluation of surface cracking (severity and frequency)
5. Hardness: Qualitative evaluation of surface hardness (5=maximum)
6. Score: Sum of qualitative evaluations.

	10-25-10	10-28-1	10-28-2	10-28-3	10-28-4	10-28-5	10-28-6	10-28-7	10-28-8
REACTION TIME(min)	5	0	N/A	0	9	0	0	5	0
SETTING TIME(min)	0	0	1 DAY	30	30	3 DAYS	0	1 DAY	0
COMMENTS:	SET CRACKED.	FLASH SET. HOT.	SET SLOWLY. NO CRACKS. DISSOLV IN WATER.	SAND MIXED WITH POWDER. LIQUID ADDED LATER.	CRACKED BADLY.	DISSOLV IN WATER.	FLASH SET.	SOME CRACKS.	FLASH SET.
EVALUATION									
VISCOSITY-	1	0	3	3	2	2	0	3	0
SET TIME-	2	0	0	3	3	3	0	4	0
CRACKING-	0	0	5	2	0	5	0	1	0
1 DAY HARDNESS-	2	0	0	2	1	0	0	1	0
7 DAY HARDNESS-	4	0	5	4	5	0	0	5	0
SCORE	9	0	13	14	11	10	0	14	0

	10-28-9	11-3-1	11-4-1	11-4-2	11-7-1	11-7-2	11-7-3	11-7-4	11-7-5
REACTION TIME(min)	20	5	5	5	5	15	5	5	5
SETTING TIME(min)	N/A	10	N/A	1 DAY	N/A	3 DAYS	1 DAY	1 DAY	20
COMMENTS:	WOULD NOT SET.	VERY MINOR CRACKING HARD.	WOULD NOT SET. CaF2 FINE.	ALMOST NO CRACKS.	DID NOT SET.	SOME SMALL CRACKS.	SOME SMALL CRACKS.	NO CRACKS.	NO CRACKS.
EVALUATION									
VISCOSITY-	5	3	3	4	2	2	2	2	2
SET TIME-	0	4	0	4	0	1	2	3	4
CRACKING-	0	4	0	4	0	4	4	5	5
1 DAY HARDNESS-	0	4	0	3	0	2	3	3	4
7 DAY HARDNESS-	0	5	0	5	0	5	5	5	5
SCORE	5	20	3	20	2	14	16	18	20

	11-7-8	11-8-1	11-8-2	11-8-3	11-8-4	11-8-5	11-9-1	11-9-2	11-9-3
REACTION TIME(min)	5	5	5	5	5	5	5	5	5
SETTING TIME(min)	N/A	20	0	1	1 DAY	1 DAY	2 DAYS	2 DAYS	1 DAY
COMMENTS:	DID NOT SET.	SOME SMALL CRACKS. INITIALLY SOFT.	FLASH SET.	INITIAL LOW VISCOS. FLASH SET. CRACKED.	BROKE ON REMOVAL FROM MOLD.	CRACKED SLIGHTLY.	CRACKED BADLY.	CRACKED SLIGHTLY.	SLIGHT CRACKS.
EVALUATION									
VISCOSITY-	2	3	0	4	2	3	3	4	5
SET TIME-	0	4	0	0	4	4	2	2	5
CRACKING-	0	4	0	1	3	3	3	4	4
1 DAY HARDNESS-	0	2	0	1	2	3	0	0	4
7 DAY HARDNESS-	0	5	0	3	3	4	5	5	5
SCORE	2	18	0	9	14	17	13	15	23

	11-9-4	11-9-5	11-9-6	11-9-7	11-9-8	11-10-1	11-10-2	11-10-3	11-10-4
REACTION TIME(min)	5	10	12	12	17	30	30	30	30
SETTING TIME(min)	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY
COMMENTS:	MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH , SAND. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.
EVALUATION									
VISCOSITY-	3	4	4	4	4	4	5	5	4
SET TIME-	5	4	5	5	5	5	5	5	5
CRACKING-	4	5	5	5	5	4	4	4	4
1 DAY HARDNESS-	4	2	3	4	4	4	4	4	4
7 DAY HARDNESS-	5	3	5	5	5	5	5	5	5
SCORE	21	18	22	23	23	22	23	23	22

	11-25-3	11-25-4
REACTION TIME(min)	30	30
SETTING TIME(min)	1 DAY	1 DAY
COMMENTS:	PERFECT SURFACE, V.HARD, SMOOTH	GOOD SURFACE, HARD, SMOOTH
EVALUATION		
VISCOSITY-	5	5
SET TIME-	5	5
CRACKING-	5	5
1 DAY HARDNESS-	5	4
7 DAY HARDNESS-	5	4
SCORE	25	23

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-1	gram	40.0	60.0				13.7	113.7	100	1.5	1.5
	% wet	35.2	52.8				12.0				
	% dry	40.0	60.0								
H-2	gram	20.0	80.0				47.4	147.4	100	4.0	4
	% wet	13.6	54.3				32.2				
	% dry	20.0	80.0								
H-3	gram	20.0	40.0	40.0			20.6	120.6	100	2.0	4
	% wet	16.6	33.2	33.2			17.1	100.0			
	% dry	20.0	40.0	40.0							
H-4	gram	20.0	40.0	20.0	20.0		33.5	133.5	100	2.0	4
	% wet	15.0	30.0	15.0	15.0		25.1	100.0			
	% dry	20.0	40.0	20.0	20.0						
H-5	gram	20.0	40.0	20.0	20.0		10.6	110.6	100	2.0	4
	% wet	18.1	36.2	18.1	18.1		9.6	100.0			
	% dry	20.0	40.0	20.0	20.0						
H-6	gram	20.0	30.0	40.0	10.0		3.2	103.2	100	1.5	4
	% wet	19.4	29.1	38.8	9.7		3.1	100.0			
	% dry	20.0	30.0	40.0	10.0						
H-7	gram	20.0	20.0	20.0	20.0	20.0	12.2	112.2	100	1.0	4
	% wet	17.8	17.8	17.8	17.8	17.8	10.9	100.0			
	% dry	20.0	20.0	20.0	20.0	20.0					

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-8	gram	20.0	20.0	20.0	20.0	20.0	17.7	117.7	100	1.0	4
	% wet	17.0	17.0	17.0	17.0	17.0	15.0	100.0			
	% dry	20.0	20.0	20.0	20.0	20.0					
H-9	gram	20.0	30.0		10.0	40.0	15.2	115.2	100	1.5	4
	% wet	17.4	26.0		8.7	34.7	13.2	100.0			
	% dry	20.0	30.0		10.0	40.0					
H-10	gram	20.0	20.0	60.0			2.9	102.9	100	1.0	4
	% wet	19.4	19.4	58.3			2.8	100.0			
	% dry	20.0	20.0	60.0							
H-11	gram	20.0	20.0	30.0		30.0	15.7	115.7	100	1.0	4
	% wet	17.3	17.3	25.9		25.9	13.6	100.0			
	% dry	20.0	20.0	30.0		30.0					
H-12	gram	50.0	65.0	50.0			11.0	176.0	165	1.3	2.3
	% wet	28.4	36.9	28.4			6.3	100.0			
	% dry	30.3	39.4	30.3							
H-13	gram	50.0	100.0	50.0			33.5	233.5	200	2.0	3
	% wet	21.4	42.8	21.4			14.3	100.0			
	% dry	25.0	50.0	25.0							
H-14	gram	20	65	15			22.9	122.9	100	3.3	4
	% wet	16.3	52.9	12.2			18.6	100.0			
	% dry	20.0	65.0	15.0							

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-15	gram	20	70	10			29.2	129.2	100	3.5	4
	% wet	15.5	54.2	7.7			22.6	100.0			
	% dry	20.0	70.0	10.0							
H-16	gram	20	60	20			27.1	127.1	100	3.0	4
	% wet	15.7	47.2	15.7			21.3	100.0			
	% dry	20.0	60.0	20.0							
H-17	gram	20	75				32.3	127.3	95	3.8	3.75
	% wet	15.7	58.9				25.4	100.0			
	% dry	21.1	78.9								
H-18	gram	14	76	20			30.3	140.3	110	5.4	6.9
	% wet	10.0	54.2	14.3			21.6	100.0			
	% dry	12.7	69.1	18.2							
H-19	gram	14	71	15			27.5	127.5	100	5.1	6.1
	% wet	11.0	55.7	11.8			21.6	100.0			
	% dry	14.0	71.0	15.0							
H-20	gram	19.95	65.05	15			20.1	120.1	100	3.3	4.0
	% wet	16.6	54.2	12.5			16.7	100.0			
	% dry	20.0	65.1	15.0							
H-21	gram	30.1	60.9	30			7.9	128.9	121	2.0	3.0
	% wet	23.4	47.2	23.3			6.1	100.0			
	% dry	24.9	50.3	24.8							

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-22	gram	30.1	69.9	20			9.2	129.2	120	2.3	3.0
	% wet	23.3	54.1	15.5			7.1	100.0			
	% dry	25.1	58.3	16.7							
H-23	gram	17.5	67.5	15			18.3	118.3	100	3.9	4.7
	% wet	14.8	57.1	12.7			15.5	100.0			
	% dry	17.5	67.5	15.0							
H-24	gram	301	699	200			127.3	1327.3	1200	2.3	3.0
	% wet	22.7	52.7	15.1			9.6	100.0			
	% dry	25.1	58.3	16.7							
H-25	gram	250.81	582.49	166.7			211.9	1211.9	1000	2.3	3.0
	% wet	20.7	48.1	13.8			17.5	100.0			
	% dry	25.1	58.2	16.7							
H-26	gram	199.5	650.5	150			333.1	1333.1	1000	3.3	4.0
	% wet	15.0	48.8	11.3			25.0	100.0			
	% dry	20.0	65.1	15.0							
H-27	gram	20	40	40			22.3	122.3	100	2.0	4.0
	% wet	16.4	32.7	32.7			18.2	100.0			
	% dry	20.0	40.0	40.0							
H-28	gram	19.95	65.05	15			27.5	127.5	100	3.3	4.0
	% wet	15.6	51.0	11.8			21.6	100.0			
	% dry	20.0	65.1	15.0							

NOTES:
1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-29	gram	30.1	69.9	20			20	140.0	120	2.3	3.0
	% wet	21.5	49.9	14.3			14.3	100.0			
	% dry	25.1	58.3	16.7							
H-30	gram	50		40	10		2.1	102.1	100	0.2	1.0
	% wet	49.0		39.2	9.8		2.1	100.0			
	% dry	50.0		40.0	10.0						
H-31	gram	40		50	10		4.1	104.1	100	0.25	1.5
	% wet	38.4		48.0	9.6		3.9	100.0			
	% dry	40.0		50.0	10.0						
H-32	gram	50		30	20		6.3	106.3	100	0.4	1.0
	% wet	47.0		28.2	18.8		5.9	100.0			
	% dry	50.0		30.0	20.0						

NOTES:
1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 3(a): FLY ASH BASED GEOPOLYMER CEMENT MIX DESIGNS
(gram amounts)

	GP52	ASH	SAND	WATER	Total (wet)	Total(dry)
12-29-1	50	50		18.6	118.6	100
12-29-2	50	50		10	110	100
12-29-3	50	50	25	29.2	154.2	125
12-29-4	50	50	25	15	140	125
12-29-5	50	50	50	20	170	150
12-29-6	50	75		19.5	144.5	125
12-29-7	50	75		21	146	125
12-29-8	50	75		26	151	125
12-29-9	25	37.5	12.5	15	90	75
12-29-10	25	37.5	25	20	107.5	87.5
12-29-11	25	37.5	37.5	23	123	100
12-29-12	25	37.5	37.5	20	120	100
12-29-13	25	50		27	102	75
12-29-14	25	50		16	91	75
12-29-15	25	50	12.5	19	106.5	87.5
12-29-16	25	50	25	22	122	100

TABLE 3(b): FLY ASH BASED GEOPOLYMER CEMENT MIX DESIGNS
(weight percentage basis, excluding water)

	GP52	ASH	SAND	ASH:GP	AGGREGATE:GP
12-29-1	50	50	0	1	1
12-29-2	50	50	0	1	1
12-29-3	40	40	20	1	1.5
12-29-4	40	40	20	1	1.5
12-29-5	33	33	33	1	2
12-29-6	40	60	0	2	1.5
12-29-7	40	60	0	2	1.5
12-29-8	40	60	0	2	1.5
12-29-9	33	50	17	2	2
12-29-10	29	43	29	2	2.5
12-29-11	25	38	38	2	3
12-29-12	25	38	38	2	3
12-29-13	33	67	0	2	2
12-29-14	33	67	0	2	2
12-29-15	29	57	14	2	2.5
12-29-16	25	50	25	2	3

TABLE 4(a): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(gram amounts)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SLAG	FLY ASH	Gram Total	SET TIME (min)
20-6-1	18.0	27.0	55.0	70.0				170.0	3
20-6-2	22.5	22.5	55.0	70.0				170.0	4
20-6-3	27.0	18.0	55.0	70.0				170.0	5.25
20-6-4	31.5	13.5	55.0	70.0				170.0	9
20-6-5	36.0	9.0	55.0	70.0				170.0	0.5
20-6-6	22.5	22.5	55.0	70.0				170.0	4
20-6-7	22.5	22.5	55.0	70.0				170.0	4
20-6-8	27.0	18.0	55.0	93.1				193.1	-
20-6-9	20.0	20.0	60.0	70.0				170.0	6
20-6-10	25.0	25.0	50.0	70.0				170.0	2
20-6-11	9.6	9.6	45.0	100.1				164.3	13
6-21-1	22.5	22.5	55.0		90.0			190.0	
6-21-2	13.5	13.5	33.0	30.0	50.0			140.0	1-2
6-21-2(A)	13.5	13.5	33.0	30.0	50.0			140.0	5
6-21-3	5.1	5.1	12.4	5.0	22.5			50.0	1-2
6-22-1	4.5	4.5	13.5	5.0	22.5			50.0	1-2
6-22-2	5.1	5.1	12.4	10.0	15.0			47.5	
6-26-1	7.9	7.9	19.3	13.2	15.0			63.2	
6-26-2	7.9	7.9	19.3	11.9	15.0			61.9	
6-26-3	3.8	3.8	9.4	10.0	30.0			57.1	
6-26-4	2.0	2.0	6.0	10.0	30.0			50.0	
6-26-5	3.5	3.5	13.1	20.7	61.4			102.3	
6-28-1	11.2	11.2	27.5		50.0			99.9	7.5

TABLE 4(a): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(gram amounts)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SLAG	FLY ASH	Gram Total	SET TIME (min)
6-28-2	11.2	11.2	27.5		50.0			99.9	6
6-28-3	11.2	11.2	27.5		41.0			90.9	5
6-28-4	11.2	11.2	27.5		50.0			99.9	5
7-7-1	13.2	13.2	32.4	41.2				100.0	4
7-7-2	13.2	13.2	32.4	41.2				100.0	4
7-7-3	13.2	13.2	32.4	41.2				100.0	4
7-7-4	13.2	9.9	32.4	41.2		3.3		100.0	5
7-7-5	13.2	6.6	32.4	41.2		6.6		100.0	12
7-7-6	13.2	3.3	32.4	41.2		9.9		100.0	
7-22-2	10.0	10.0	20.0		20.0	20.0		80.0	
7-22-3	10.0	10.0	20.0		40.0			80.0	
7-22-4	12.5	12.5	25.0	20.0	30.0			100.0	
7-22-5	8.8	8.8	17.5	15.0	35.0	15.0		100.0	
7-22-6	8.8	8.8	17.5		65.0			100.0	
7-22-7	7.5	7.5	15.0	90.0	30.0			150.0	

TABLE 4(b): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(weight percentages)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SAND	FLY ASH	SET TIME (min)
20-6-1	10.6%	15.9%	32.4%	41.2%				3
20-6-2	13.2%	13.2%	32.4%	41.2%				4
20-6-3	15.9%	10.6%	32.4%	41.2%				5.25
20-6-4	18.5%	7.9%	32.4%	41.2%				9
20-6-5	21.2%	5.3%	32.4%	41.2%				0.5
20-6-6	13.2%	13.2%	32.4%	41.2%				4
20-6-7	13.2%	13.2%	32.4%	41.2%				4
20-6-8	14.0%	9.3%	28.5%	48.2%				-
20-6-9	11.8%	11.8%	35.3%	41.2%				6
20-6-10	14.7%	14.7%	29.4%	41.2%				2
20-6-11	5.8%	5.8%	27.4%	60.9%				13
6-21-1	11.8%	11.8%	28.9%		47.4%			
6-21-2	9.6%	9.6%	23.6%	21.4%	35.7%			5
6-21-2(A)	9.6%	9.6%	23.6%	21.4%	35.7%			
6-21-3	10.1%	10.1%	24.8%	10.0%	45.0%			
6-22-1	9.0%	9.0%	27.0%	10.0%	45.0%			
6-22-2	10.7%	10.7%	26.1%	21.1%	31.6%			
6-26-1	12.5%	12.5%	30.5%	20.9%	23.7%			
6-26-2	12.7%	12.7%	31.1%	19.2%	24.2%			
6-26-3	6.7%	6.7%	16.5%	17.5%	52.5%			
6-26-4	4.0%	4.0%	12.0%	20.0%	60.0%			
6-26-5	3.5%	3.5%	12.8%	20.2%	60.0%			
6-28-1	11.2%	11.2%	27.5%		50.1%			7.5
6-28-2	11.2%	11.2%	27.5%		50.1%			6

TABLE 4(b): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES

(weight percentages)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SAND	FLY ASH	SET TIME (min)
6-28-3	12.3%	12.3%	30.3%		45.1%			5
6-28-4	11.2%	11.2%	27.5%		50.1%			5
7-7-1	13.2%	13.2%	32.4%	41.2%				4
7-7-2	13.2%	13.2%	32.4%	41.2%				4
7-7-3	13.2%	13.2%	32.4%	41.2%				4
7-7-4	13.2%	9.9%	32.4%	41.2%	3.3%	3.3%		5
7-7-5	13.2%	6.6%	32.4%	41.2%	6.6%	6.6%		12
7-7-6	13.2%	3.3%	32.4%	41.2%	9.9%	9.9%		
7-22-2	12.5%	12.5%	25.0%		25.0%	25.0%		
7-22-3	12.5%	12.5%	25.0%		50.0%			
7-22-4	12.5%	12.5%	25.0%	20.0%	30.0%			
7-22-5	8.8%	8.8%	17.5%	15.0%	35.0%	15.0%		
7-22-6	8.8%	8.8%	17.5%		65.0%			
7-22-7	5.0%	5.0%	10.0%	60.0%	20.0%			

TABLE 4(c): EFFECT OF COMPONENT RATIOS ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-1	1.5	1.2	0.7	3
20-6-2	1.0	1.2	0.7	4
20-6-3	0.7	1.2	0.7	5.25
20-6-4	0.4	1.2	0.7	9
20-6-5	0.3	1.2	0.7	0.5
20-6-6	1.0	1.2	0.7	4
20-6-7	1.0	1.2	0.7	4
20-6-8	0.7	1.2	0.9	-
20-6-9	1.0	1.5	0.7	6
20-6-10	1.0	1.0	0.7	2
20-6-11	1.0	2.3	1.6	13

TABLE 4(d): EFFECT OF CEMENT CONTENT ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-1	1.5	1.2	0.7	3
20-6-2	1.0	1.2	0.7	4
20-6-3	0.7	1.2	0.7	5.25
20-6-4	0.4	1.2	0.7	9

TABLE 4(e): EFFECT OF LIQUID:POWDER RATIO ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-10	1.0	1.0	0.7	2
20-6-6	1.0	1.2	0.7	4
20-6-9	1.0	1.5	0.7	6
20-6-11	1.0	2.3	1.6	13

TABLE 5(a): MIX DESIGNS USED FOR STRENGTH TESTING
(gram amounts)

	GP(A)	GP(B)	AGGREGATE		Fly Ash
			Coarse	Fine	
2-7-1	11	9	45	135	
2-7-2	22	18	40	120	
2-7-3	33	27	35	105	
2-7-4	22	18	40	120	
2-7-5	20	20	60	100	
2-7-6	20	20	80	80	
2-7-7	20	20	100	60	
2-7-8	20	20	120	40	
2-7-33	17	13	42	128	
2-7-34	28	22	38	112	
2-8-9	22	14	40	120	4
2-8-10	22	10	40	120	8
2-8-11	22	6	40	120	12
2-8-12	22		40	120	18
2-8-13	18	18	40	124	
2-8-14	14	18	42	126	
2-8-15	10	18	42	130	
2-8-16	6	18	44	132	
2-8-17	18	18	40	120	4
2-8-18	14	18	40	120	8
2-8-19	10	18	40	120	12
2-8-20	6	18	40	120	16
2-7-2(a)	400	400	800	2400	

TABLE 5(b): MIX DESIGNS USED FOR STRENGTH TESTING
(weight percentages)

	GP(A)	GP(B)	AGGREGATE		Fly Ash	Testing Age	L/D Ratio	Density (kg/cu. m)	Strength (MPa)
			Coarse	Fine					
2-7-1	5.5%	4.5%	22.5%	67.5%		n/a	n/a	n/a	n/a
2-7-2	11.0%	9.0%	20.0%	60.0%		2	0.883	2211	2.8
2-7-3	16.5%	13.5%	17.5%	52.5%		2	0.946	2303	9.4
2-7-4	11.0%	9.0%	20.0%	60.0%		2	0.882	2142	6.3
2-7-5	10.0%	10.0%	30.0%	50.0%		2	0.883	2295	5.7
2-7-6	10.0%	10.0%	40.0%	40.0%		2	0.875	2331	3.9
2-7-7	10.0%	10.0%	50.0%	30.0%		2	0.916	2354	16.2
2-7-8	10.0%	10.0%	60.0%	20.0%		2	0.883	2408	13.9
2-7-33	8.5%	6.5%	21.0%	64.0%		2	0.884	2243	1.9
2-7-34	14.0%	11.0%	19.0%	56.0%		2	0.896	2214	4.6
2-8-9	11.0%	7.0%	20.0%	60.0%	2.0%	2	0.894	2174	2.6
2-8-10	11.0%	5.0%	20.0%	60.0%	4.0%	2	0.875	2219	0.9
2-8-11	11.0%	3.0%	20.0%	60.0%	6.0%	2	0.879	2178	0.9
2-8-12	11.0%		20.0%	60.0%	9.0%	n/a	n/a	n/a	n/a
2-8-13	9.0%	9.0%	20.0%	62.0%		2	0.852	2216	1.8
2-8-14	7.0%	9.0%	21.0%	63.0%		2	0.885	2225	1.3
2-8-15	5.0%	9.0%	21.0%	65.0%		2	0.842	2224	0.9
2-8-16	3.0%	9.0%	22.0%	66.0%		n/a	n/a	n/a	n/a
2-8-17	9.0%	9.0%	20.0%	60.0%	2.0%	2	0.884	2243	3.2
2-8-18	7.0%	9.0%	20.0%	60.0%	4.0%	2	0.88	2265	3.0
2-8-19	5.0%	9.0%	20.0%	60.0%	6.0%	2	0.826	2276	0.9
2-8-20	3.0%	9.0%	20.0%	60.0%	8.0%	2	0.874	2179	0.3
2-7-2(a)	10.0%	10.0%	20.0%	60.0%		2	1.968	2158	6.1

TABLE 5(c): TEST OF STRENGTH DEVELOPMENT OVER TIME
(weight percentages)

			AGGREGATE		Testing	L/D	Density	Strength
	GP(A)	GP(B)	Coarse	Fine	Age	Ratio	(kg/cu. m)	(MPa)
4-7-2	4.7	7.8	50	37.5	3	2.0	2374	13.7
4-7-2	4.7	7.8	50	37.5	7	2.0	2392	19.8
4-7-2	4.7	7.8	50	37.5	31	2.0	2390	33.6
4-7-2(a)	4.7	7.8	50	37.5	31	2.1	2461	9.4

NOTE: Water added to cylinder 4-7-2(a)

TABLE 6: MIX DESIGNS USING DIFFERENT BINDERS AND AGGREGATES IN CONCRETE MIXES
(constituents as weight percent)

	GPA LIQUID	IB7030 LIQUID	IB CTIVATOR	INORBOND TYPE D	INORBOND TYPE F	SILICA FUME	SLAG	CaF2	SAND	PEA GRAVEL	SET TIME
3-16-1	23.8%		9.5%	9.5%					28.6%	28.6%	5 min
3-16-2	23.8%		4.8%	9.5%			4.8%		28.6%	28.6%	Next day
3-16-3	23.8%		3.8%	9.5%		1.0%	3.8%	1.0%	28.6%	28.6%	Next day
3-16-4	20.0%		3.2%	4.0%		0.8%	6.0%	2.0%	40.0%	24.0%	Next day
3-16-5	20.0%		4.0%	5.0%		1.0%	7.5%	2.5%	30.0%	30.0%	Next day
3-16-6	21.4%		2.9%	3.6%		0.7%	5.4%	1.8%	42.9%	21.4%	Next day
4-3-1	23.1%		9.3%		9.3%				58.3%		20 min.
4-3-2	23.1%		9.3%		9.3%				58.3%		25 min.
4-1-3	16.3%		6.5%		6.5%				65.1%		20 min.
12-15-1		20.8%		8.3%		0.8%	4.2%	3.3%	62.5%		30 min.
12-15-2		20.8%		8.3%		0.8%	5.0%	2.5%	62.5%		30 min.
12-15-3		9.5%		9.5%		1.0%	6.7%	1.9%	71.4%		30 min.
12-15-4		9.5%		9.5%		1.0%	2.9%	5.7%	71.4%		30 min.

Table 7(a): Solidification of Iron Hydroxide Sludge
(gram amounts)

	GPA	GPB	Fly Ash	Sand	Sludge	Total
H-1	25	25		50	100	200
H-2	25	25	50	50	50	200
H-3	25	25	75	25	50	200
H-4	15	15	70	25	75	200
H-1a	25	25			150	200
H-1b	12.5	12.5	50		150	225

Table 7(b): Solidification of Iron Hydroxide Sludge
(weight percentages)

	GPA	GPB	Fly Ash	Sand	Sludge	Comments
H-1	12.5%	12.5%		25.0%	50.0%	
H-2	12.5%	12.5%	25.0%	25.0%	25.0%	Sample sent to P. Goudey
H-3	12.5%	12.5%	37.5%	12.5%	25.0%	Sample sent to P. Goudey
H-4	7.5%	7.5%	35.0%	12.5%	37.5%	Sample sent to P. Goudey
H-1a	12.5%	12.5%			75.0%	
H-1b	5.6%	5.6%	22.2%		66.7%	

TABLE 1

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-7-1	Feb. 7	Feb. 9	2 Day Dry Cure	0.883	2408	-	13.9
2-7-2	"	"	"	0.880	2211	-	2.7
2-7-3	"	"	"	0.946	2303	-	9.4
2-7-4	"	"	"	0.882	2142	-	6.3
2-7-5	"	"	"	0.883	2295	-	5.7

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-7-1: 4.67 cm; 2-7-2: 4.68 cm; 2-7-3: 4.67 cm; 2-7-4: 4.67 cm; 2-7-5: 4.68 cm.

MAXIMUM AGGREGATE SIZE: "Pea" Gravel.

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders approximately 4.2 cm high.
Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 2

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-7-6	Feb. 7	Feb. 9	2 Day Dry Cure	0.875	2331	-	3.9
2-7-7	"	"	"	0.916	2354	-	16.2
2-7-33	"	"	"	0.884	2243	-	1.9
2-7-34	"	"	"	0.896	2214	-	4.6

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-7-6: 4.68 cm; 2-7-7: 4.67 cm; 2-7-33: 4.67 cm; 2-7-34: 4.67 cm.

MAXIMUM AGGREGATE SIZE: "Pea" Gravel.

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders approximately 4.2 cm high. Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 3

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressiv Strength (MPa)
2-8-9	Not Provided	Feb. 10	2 Day Dry Cure	0.894	2174	-	2.6
2-8-10	"	"	"	0.875	2219	-	0.9
2-8-11	"	"	"	0.879	2178	-	0.9
2-8-13	"	"	"	0.852	2216	-	1.8
2-8-14	"	"	"	0.885	2225	-	1.3

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-8-9: 4.65 cm; 2-8-10: 4.65 cm; 2-8-11: 4.66 cm; 2-8-13: 4.68 cm; 2-8-14: 4.65 cm.

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 4

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-8-15	Not Provided	Feb. 10	2 Day Dry Cure	0.842	2224	-	0.9
2-8-17	"	"	"	0.884	2243	-	3.2
2-8-18	"	"	"	0.880	2265	-	3.0
2-8-19	"	"	"	0.826	2276	-	0.9
2-8-20	"	"	"	0.874	2179	-	0.3

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-8-15: 4.66 cm; 2-8-17: 4.65 cm; 2-8-18: 4.65 cm; 2-8-19: 4.63 cm; 2-8-20: 4.57 cm.

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 4

COMPRESSIVE STRENGTH ~~CORE~~ CYLINDER TEST REPORT

DATE: APRIL 10, 1989

PROJECT: COMPRESSIVE STRENGTH TESTING PROJECT NO: 891-1111

CLIENT: D. COMRIE CONSULTING LTD.

LOCATION ON PROJECT: -

Core No.	Date Sampled	Date Tested	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	-	APR. 10/89	DRY	2.0	2374	-	13.7

DIRECTION APPLIED LOAD: AXIAL

DIAMETER OF CORE: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm ?

APPROXIMATE CONCRETE AGE: 3 DAYS

APPEARANCE: CYLINDER CONTAINED HONEYCOMBED AREAS ON EXTERIOR

REMARKS: OF CYLINDER!

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 5

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4" x 8"	Not Provided	Feb. 10	2 Day Dry Cure	1.968	2158	-	6.1

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 5

COMPRESSIVE STRENGTH ~~CORE~~ CYLINDER TEST REPORT

DATE: APRIL 10, 1989

PROJECT: COMPRESSIVE STRENGTH TESTING

PROJECT NO: 891-1111

CLIENT: D. COMRIE CONSULTING LTD

LOCATION ON PROJECT: —

Core No.	Date ~~Sampled~~ CAST	Date Tested	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	APR. 7/89	APR. 14/89	DRY	2.0	2392	—	19.8

DIRECTION APPLIED LOAD: AXIAL

DIAMETER OF CORE: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19mm ?

APPROXIMATE CONCRETE AGE: 7 DAY

APPEARANCE: CYLINDER CONTAINED HONEYCOMING ON EXTERIOR FACE.

REMARKS:

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 6

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4" x 8"	Not Provided	Apr. 7	Dry	2.0	2310	-	5.2

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm

APPROXIMATE CONCRETE AGE: Not provided

APPEARANCE: Shrinkage cracks noted on ends only.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 7

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing
of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	Not Provided	Apr. 10	Dry	2.0	2374	-	13.7
(4"x 8")							

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm

APPROXIMATE CONCRETE AGE: 3 days

APPEARANCE: Cylinder contained honeycombed areas on exterior.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 8

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT NO: 891-1111

PROJECT: Compressive Strength Testing
of Mini Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	Apr. 7	Apr. 14	Dry	2.0	2392	-	18.3
(4"x 8")							

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm ?

APPROXIMATE CONCRETE AGE: 7 days

APPEARANCE: Cylinder contained honeycombing on exterior face.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 9

COMPRESSIVE STRENGTH ~~CORE~~ CYLINDER TEST REPORT

DATE: May 12/1989.

PROJECT NO:

PROJECT: Compressive Strength Testing of 4"x8" Cylinders

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

~~Core~~ CYLINDER No.	Date ~~Sampled~~ SUPPLIED	Date Tested	Test Condition	L/D Ratio	Density (kg/m³)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2-A	May 8/89	May 8/89	DRY	2.1	2390	/	33.6
4-7-2-B	"	"	"	2.1	2461		9.4

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CORE: 10.1 cm ; 10.1 cm

MAXIMUM AGGREGATE SIZE: —

APPROXIMATE CONCRETE AGE: ?

APPEARANCE: Good.

REMARKS:

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

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APPENDIX 3. PROGRESS REPORTS-PHASE 1 WORK

INTERIM REPORT 1

Source: HALREPT1

PROGRESS REPORT

Contract Title:	To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.
Contract No:	23440-8-9171/01-SQ

Mix Designs

Several preliminary tests have been conducted to evaluate the performance of geopolymer when combined with various constituents. Fly ash, silica fume, clay and sand have been used in different proportions, as shown in the enclosed table. Where necessary, water has been added for ease of mixing.

These mixes serve to provide an indication of the effect of including different constituents with geopolymer, and form a basis from which mix designs can be developed.

Samples were qualitatively evaluated on the basis of compressive strength, hardness (Moh's scale), the consistency of the wet mixture and the ability of the mix to conform to the surfaces of a mold (mouldability). Since the aim of this program is to develop a mix which can be applied to an irregular surface (i.e., pyritic slates), it is worthwhile examining this ability to conform.

The contributions made by individual constituents are discussed below.

Fly Ash

A relatively low temperature fly ash was obtained from Ontario Hydro's Lakeview generating station in Mississauga.

The addition of large amounts of fly ash requires corresponding large amounts of moisture in the mix. If the geopolymer itself does not provide sufficient moisture, relatively large volumes of water must be added. Since water acts to weaken the strength and hardness of the final product, this addition poses a problem.

INTERIM REPORT 2

Source: HALREPT2

PROGRESS REPORT

Contract Title:	To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.
Contract No:	23440-8-9171/01-SQ

Several preliminary tests have been conducted to evaluate the performance of geopolymer when combined with various constituents. Fly ash, silica fume, clay and sand have been used in different proportions, as shown in the enclosed table. Where necessary, water has been added for ease of mixing.

These mixes provide an indication of the effect of including different constituents with geopolymer. The next phase of this program will involve systematic development of mix designs using these constituents.

Samples were qualitatively evaluated on the basis of compressive strength, hardness (Moh's scale), the consistency of the wet mixture and the ability of the mix to conform to the surfaces of a mold (moldability). Since the aim of this program is to develop a mix which can be applied to an irregular surface (i.e., pyritic slates), it is worthwhile examining this ability to conform.

The contributions made by individual constituents are discussed below.

Fly Ash

A relatively low temperature fly ash was obtained from Ontario Hydro's Lakeview generating station in Mississauga.

The addition of large amounts of fly ash requires corresponding large amounts of moisture in the mix, which can result in a product of lower strength and hardness. Mixtures containing up to 60 weight percent ash and 40 weight percent geopolymer (on a dry weight basis) have produced solids of high strength and hardness.

Mixtures with higher ash contents can be achieved by pre-mixing geopolymer with the fly ash. Normally, wet and dry ingredients in the geopolymer are combined in a 1:1 ratio. An ash-based geopolymer employing 50 weight percent geopolymer liquid, 30 weight percent fly ash and 20 weight percent geopolymer powder was used for a number of mixes. Compositions with as little as 13 weight percent of this ash-based geopolymer and 69 weight percent additional ash (on a dry weight basis) have produced solids, although at some considerable expense of set-up time, strength and hardness.

Sand Content

A fine, commercially available playbox sand of moderate purity was employed in the testing.

A comparison of mixes incorporating sand with mixes solely composed of geopolymer and fly ash demonstrates that sand acts to increase strength, hardness and improves ease of mixing.

The use of sand in silica fume based mixes also increases strengths, and also results in increased moldability. Replacing a portion of clay with sand in clay based mixes also results in improved strength and hardness.

Clay Content

A fine, dry (but uncalcined) montmorillonite clay (Tennessee No. 5, with an Al_2O_3/SiO_2 ratio of 2.11) was employed in some mix designs.

As expected, the substitution of sand by clay requires more water to be added to the mix and results in samples of lower hardness and strength. Similar relations are observed in the substitution of clay for fly ash. However, the use of clay in the place of fly ash does seem to increase the moldability of the mixture.

Increasing clay content at the expense of sand also results in decreased strengths and mixes of an increasingly paste-like nature.

Silica Fume

The addition of silica fume imparts a grainy texture to the mix, making mixing easier and requiring less water. Where silica fume is added at the expense of sand, more water is required for mixing but a product of higher strength and hardness results.

Water Content
Mixtures have been prepared both with and without water. Dry or paste-like mixtures, having only the moisture provided by the geopolymer, are difficult to mix and are more suitable for extrusion molding processes. Wet mixes are more easily mixed and can be designed to produce consistencies ranging from mortar-like to a syrup.

Water, in large proportions, will of course dilute the geopolymer and render the mixture useless. However, small increases in the amount of water can produce dramatic changes in the consistency of the mix. An increase of as little as 5 weight percent water can make the difference between a dry, paste-like mixture and a smooth, easily molded mixture.

Summary

Two types of criteria have been used to asses the mixing done to date: physical characteristics (moldability of the mixture, strength and hardness of the final product) and economics (represented by the ratio of geopolymer to other filler ingredients). Based on this criteria, mix H-8 stands out as the best performing, containing 20 weight percent (on a dry basis) geopolymer, as shown below:

Mix Design	GP (%)	Ash (%)	Sand (%)	Fume (%)	Water (%)
H-8 (dry basis)	20	20	20	20	-
H-8 (wet basis)	17	17	17	17	15

The next step in the project will be a systematically engineered mix design, which will be based, in part, on the data collected so far.

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INTERIM REPORT 3

Source: HBILL2
Date: February 21, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Work reported in this period includes a meeting in Ottawa with the Scientific Authority, followed by preparation of a number of geopolymer based mixes.

A meeting was held on February 1 with the Scientific Authority in order to discuss the progress made to date on the project, and the direction which it should proceed in from this point. Technical tests, such as freeze/thaw and permeability, which will be carried out on the samples produced during the contract, were also discussed.

Several mixing programs were developed, each designed to evaluate the effect of different factors. A number of samples were made for each program, and the results of compressive strength testing on these samples will be used to define curves based on the following variables:

1) Compressive strength as a function of geopolymer content
2) Compressive strength as a function of percent coarse aggregate in the total aggregate fraction.
3) Effect of fly ash on compressive strength when substituted for the powder portion of geopolymer.
4) Effect on compressive strength when the liquid portion of geopolymer is reduced.
5) Effect of fly ash on compressive strength when substituted for the liquid portion of geopolymer.

Several other variables have yet to be evaluated in the mixing program.

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INTERIM REPORT 4

Source: HALFX4

September 29, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Time has been expended on the Physical Testing and Application Trials portions of the project. Discussions have been held with the Scientific Authority and with concrete contractors in order to prepare for both physical testing and a "field test" of various mixes for shotcreting.

Freeze Thaw molds have been requested of, and received from, CANMET in Ottawa. Beams will be poured following the actual shotcreting test, assuming that the mix designs perform satisfactorily under shotcreting.

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INTERIM REPORT 5

December 4, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Work conducted during this period concentrated on a field application of inorganic binder using shotcreting technology. This was considered immensely successful, since it was found that high pressure pumping of the liquid and solid portions of the binder allowed delivery of a quick setting mixture with minimal amounts of the binder liquid (representing the more expensive component). The liquid:solid ratio represents a dramatic improvement over ratios which have been previously worked with on a bench scale.

Standard 8-inch ASTM cylinders were cast with binder pumped out of shotcreting apparatus, and six beams were poured for freezing and thawing tests. After moist curing under burlap, the cylinders and four of the beams were delivered to CANMET's Materials Testing laboratories in Ottawa. Unconfined compressive strength tests will be conducted on the cylinders; the beams will be subjected to rapid freeze-thaw testing. Two beams were retained at Comrie Consulting in case beams were damaged en route to Ottawa or during the freeze-thaw testing.

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